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THE RELATION BETWEEN FIELD BRIGHTNESS AND THE SPEED OF RETINAL IMPRESSION—II

BY PERCY W. COBB

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In a previous communication of similar title[1] certain results were presented in which the time of action of a small black dot on a white screen was measured, just necessary in order that the presence of the dot could be correctly reported. It was found empirically that the relation between the necessary exposure time and the brightness of the screen could be expressed with fair accuracy by the statement that the reciprocal of the exposure time was proportional to the logarithm of the field brightness over the range of brightness used, about 1 to 100 millilamberts, corresponding closely to the same number of foot-candles illumination upon a white surface.

It is to be noted that the task set the subjects was simply to report whether the dot appeared to be present or not, with no requirement to recognize and report upon form or detail. In the work about to be described two variations have been introduced. First, the element of form is added. Two different test objects were used which the subject was required to discriminate. And second, the test object, instead of appearing upon a clear field as before, was presented as immediately replacing a pattern in the visual field, and was terminated at the end of the exposure time by being in turn

[1] JOUR. EXP. PSYCHOL., VI., 1923, pp. 138–160.

immediately replaced by another similar pattern. The element thereby introduced is one present in most of our acts of vision, notably in reading, where one group of letters after another occupies the functioning area of the retina, and where therefore the passing retinal impression is more or less of an obstacle to the effectiveness of the present one.

Historical

It cannot truthfully be said that the time relations of visual stimulation have constituted a neglected field of research, for in the literature there is no lack of reports on such subjects as the rise and fall of sensation, the time threshold of stimulation, the threshold interval between stimuli, after-images, adaptation, and the phenomena and time relations of flicker. But the writer has to date encountered only one piece of work in which the complication arising from the exposure of the same part of the retina successively to different patterns has been a factor of central interest. Dodge [2] has called attention to the importance of what he calls the 'clearing-up' process in each event of such a series, which is in effect the dying out of the retinal process due to the preceding image, accompanied or followed by the establishment of the effect of the present one; which, of course, in turn gives way in a similar manner to the next. Experimentally, our interest centers on one of these which we may, following the usage of Dodge, call the 'exposure'; the preceding and following he terms the 'preëxposure' and 'post-exposure' respectively. If the exposure is a word, Dodge finds the word to be legible in about 30σ when the preëxposure is a uniform black and the postexposure a uniform white. With this duration the word is not legible when the three are presented in the reverse order: white, exposure, black. Even with longer times the former case yields a clearer perception than the latter. With the pre- and postexposure fields divided, half black and half white, a maximum of interference took place at and near the place occupied by the dividing line,

[2] Dodge, R., 'An Experimental Study of Visual Fixation,' *Psychol. Rev. Monog. Suppl.*, 1907, No. 35, p. 95 ff. Also, in German; *Zeitsch. f. Psychol.*, *52*, 1909, pp. 321–424.

and finally, after trying lines of varying width and disposition ruled on white pre- and postexposure fields, he concludes that the disturbance to the clearing-up of a word is maximal when the pre- and postexposure patterns are of exactly the same character as the exposure, as when they also are words. Under these conditions, the time of exposure necessary for legibility was 60σ. When a series of several words had to be read 100σ were required for each. Dodge recognizes the grade of illumination of the exposure field as a factor in the result, but since the experiments mentioned constitute only a part of his study, the effect of the general level of brightness on the delay in clearing-up was not investigated by him.

The Present Work

The general arrangement of apparatus and light is the same as that described in the former communication.[1] The test object (exposure) and the devising of the means for arriving at the proper succession of the three: preëxposure, test object and postexposure, involved radical changes in the arrangement of apparatus, which changes, however, did not require any essential alteration except at the screen and behind it. Except as specified below the conditions of experimentation are identical with those of the earlier work cited, from which Fig. 1 is here reproduced.

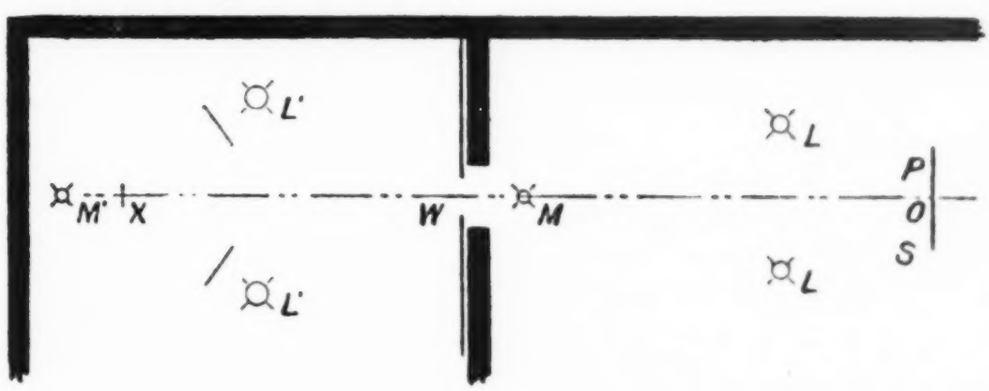


Fig. 1

Fig. 1. General plan of the apparatus. The subject was seated with his eyes at *X*, and saw the screen *S* completely filling the wall opening *W*. The preëxposure, test-object and postexposure were shown as images at *O*, the center of the screen (see Fig. 2). The fixation point was at *P*, two degrees to the left of *O*. The two lamps *L* illuminated the screen, and the two *L'* illuminated the wall. These lamps were hung at the eye-level, 1.22 m. from the floor. For the two lowest brightnesses, *f* and *g*, the single lamps *M* and *M'* were used, hung 1.9 m. from the floor.

The test object, preëxposure and postexposure patterns were doubly magnified images of figures drawn with india ink on white cardboard placed at *J*, Fig. 2, and projected into the plane of the screen within a circular aperture, *O*, 5 cm.

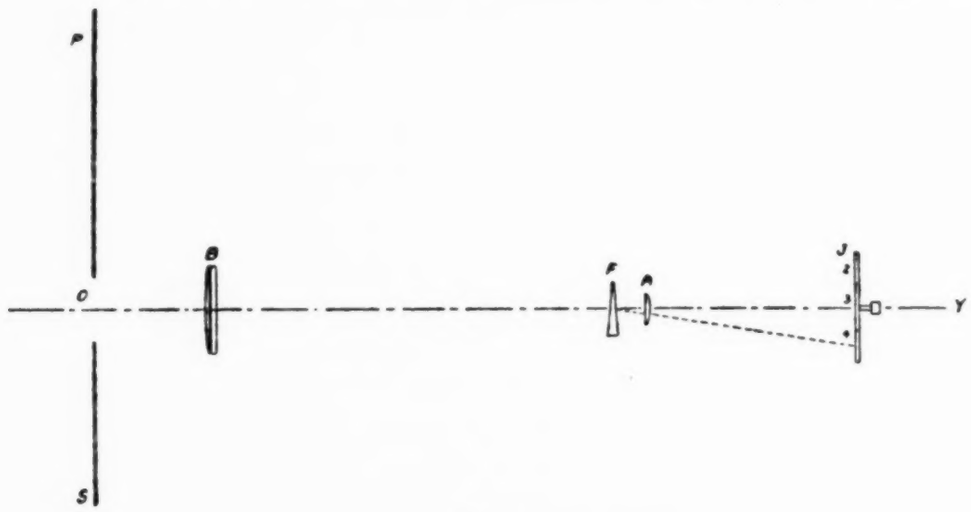


FIG. 2

FIG. 2. Scheme of the apparatus for producing the preëxposure, test-object and postexposure images at *O*. One prism only is shown at *F* as bringing the image of the area 4 into the axis at *O*, corresponding to phase 4 of the series of stimulus patterns described in the text.

in diameter, by the optical system shown. The lens *A* is a single achromatic lens of 24.8 cm. focal length. The images were seen against the face of the lens *B*, 7 cm. in diameter and of 60 cm. focal length. This lens was so placed as to project an image of the aperture of the first lens at a point on the visual axis somewhere between the subject and the screen.

To bring successively images of the various test patterns at *J* into line at *O*, three prisms and a plane glass were used at *F*. These were mounted in a frame in such a way that as the frame descended the parts of the surface at *J* were imaged at *O* as follows: (1) in the uppermost position of the frame, a point at *J* below the axis *OY*, (2) as the frame began to descend, a point to the left of the axis, (3) the axial point (the plane glass being in line) and (4) when the frame came to rest, a point to the right of the axis. The axial area (3) was, of course, in line when the plane glass was opposite the aperture of the lens *A*, and the other areas when the bases of

the corresponding prisms faced away from the axis *OY* in their respective directions. The prisms were of 1½ by 1½ inches face (38 by 38 mm.) with a deflecting power of 1 in 10. The plane glass was 1½ by ½ inches (38 by 12.7 mm.), the smaller dimension being in the line of travel of the frame, so that with uniform motion of the frame, the actual test object (3, above) was exposed just ⅓ as long as the preëxposure pattern. The frame *F* was placed approximately in conjugate focus with the eyes of the subject with respect to the lens *B*, so that the transition from one pattern to the other was seen without apparent movement.

The frame *F* was mounted in vertical guides and drawn downward by a cord passing over a driving pulley below and an idle pulley above. When not in motion, the former was held rigidly fixed by a magnetic clutch. A helical piano-wire spring was interpolated in the return side of the cord so that by grasping the cord below the spring and pulling downward, the cord was somewhat loosened about the driving pulley and the frame could be easily pulled up to its initial position ready for the next exposure.

The driving pulley was fixed on a small shaft which was a part of the clutch mechanism, outside of the bearings in which the shaft ran. Between the bearings the shaft carried an iron disc which rotated with it, and which could be held stationary by a fixed electro-magnet. Running continuously, loose on the shaft, was another electro-magnet like the first fixed to a gear of 84 teeth which was driven by a pinion of 28 teeth on a countershaft immediately below. The countershaft was driven by a small shunt-connected series electric motor through a pair of grooved cone pulleys which permitted changes of speed by steps, the fine adjustment being made by the control of the current in the field-magnets of the motor.

With current passing through the windings of both clutch magnets, the disc on the main shaft would remain tight against either magnet with which it happened to be in contact. When the current in this magnet was momentarily stopped the disc promptly flew over to the other. In the 'ready' position, with the frame at its highest point, the disc was

against the stationary magnet and the driving pulley was thereby locked. When the subject broke the circuit by a key under his hand, the disc flew over and became locked against the rotating magnet, the frame was pulled downward, aided by gravity, until it tripped a small key which broke the circuit of the rotating magnet, and the disc, shaft and pulley were again locked against the stationary one. A bumper was provided to take up the shock of the frame as it came to rest in phase 4, described above, and the cord, and the locking of the driving pulley, prevented a rebound. A small fly-wheel on the countershaft prevented noticeable retardation of the driving mechanism as the frame started on its movement downward.

The speed of the apparatus was adjusted stroboscopically. A free-spinning disc of heavy tin was driven by a small friction wheel on its own spindle, which bore against the boss of the fly-wheel on the countershaft; friction wheel and boss both being carefully sized to determine the velocity-ratio. The tin disc carried a blue-print of the stroboscope disc. This was about 120 mm. in diameter, and except for the center, was divided into 19 zones, each about $2\frac{1}{2}$ mm. wide radially. The inner zone contained 12 light and 12 dark sectors, the next three 14, 17, and 20 respectively; the next four zones just double these, and so on, the outer (19th) zone therefore containing 272 dark sectors. This pattern was originally drawn on tracing linen, and it was found that a blueprint showed better in the light used than an ordinary black photographic print. The stroboscope disc was illuminated by a 10-watt tungsten filament lamp of the regular type on a 115-volt 60-cycle alternating current. The filament of this lamp is so fine that under these conditions there is a distinct intermission in the light emitted, at the rate of 120 per second, at the reversal of the current. The zone of the disc which was nearly or exactly in step at this rate could be easily picked out. For identification the 20, 40, 80 and 160 circles were bordered with very fine india ink lines, plainly visible during rotation. The lamp was enclosed in a tin house to avoid stray light, with a small window through which the disc was illuminated.

The frequency of the alternating current had been found to vary between the limits 59 and 61 cycles. The velocity of descent of the frame was measured with a tuning fork and a smoked paper strip at various values over the range used, and found to agree well with the velocities calculated from mechanical considerations, except that at the higher velocities there were certain regular deviations, apparently due to an initial stretching of the cord, and a subsequent hastening of the descent by its elasticity. These deviations were less than 2 per cent. in extreme cases, and were corrected in the first and second sets of results by applying appropriate factors to the thresholds derived from the original series. The duration of the preëxposure as measured was found to be within 2 per cent. of its designed length (three times the exposure) except at the highest speed used, where it was about 5 per cent. below the designed value.

In the third set of results, where no pre- and postexposure patterns were used, the times of exposure were calculated without correction, since it had become apparent that the difference was negligible compared with the variability of the results from other causes.

The Test-Object and Confusion Patterns

The test-object consisted of two parallel black bars, of unit width and three units length, separated by an interval of unit

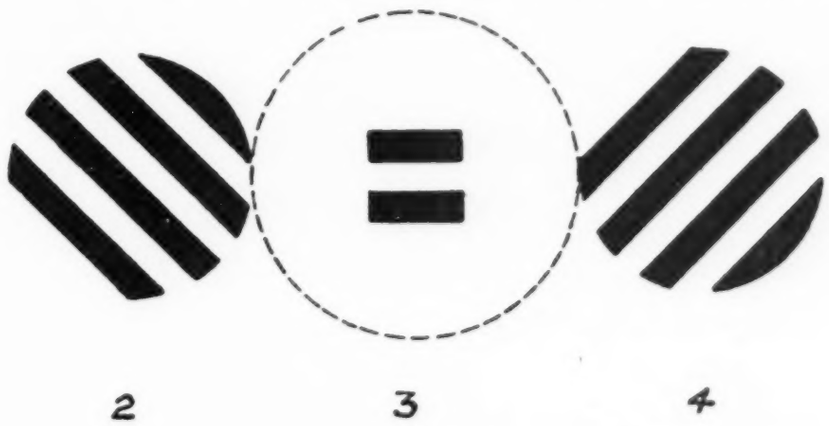


Fig. 3

Fig. 3. The preëxposure (2) and postexposure (4) patterns, and the test-object (3). This last could be turned into the vertical position. These are placed at 2, 3 and 4 respectively, Fig. 2, and appear successively to the subject as imaged in the opening *O*.

width (3, Fig. 3). This was accurately drawn on a circular white card and centered in the plane of *J*, Fig. 2, on a device which could be rotated on the axis *OY*, so that the test-object could be shown with the bars in either the vertical or the horizontal position.

The pre- and postexposure patterns, consisting of stripes and spaces of unit width covering a circular area of eight units diameter, were similarly drawn on a larger card (2 and 4, Fig. 3), cut out to expose the test-object disc, at the left and the right of the latter and at such distances that with the appropriate prism in the frame *F* opposite the aperture of the lens *A*, the corresponding pattern was imaged centrally in the opening *O*. The card surface at *J*, Fig. 2, was independently illuminated to such a point that in the image at *O*, the background of the test-object appeared of the same brightness as the adjacent portions of the screen *S*. The brightnesses of the various parts of the four phases of the exposure were then measured directly with the results following, for the various stages of brightness designated, the standard being the brightness of the test-object ground in each case (phase 3), set at unity and in parentheses:

Brightness	Phase				
	1	2	3	4	
a.....	1.07	1.04	(1.00)	1.08	Ground (card)
	—	.051	.036	.076	Figure (ink)
b.....	1.07	1.04	(1.00)	1.07	
	—	.106	.083	.144	
c.....	1.07	1.00	(1.00)	1.08	
	—	.037	.040	.101	
g.....	1.04	.93	(1.00)	1.06	
	—	.031	.040	.106	

At brightnesses *a* and *b*, *J* was illuminated by two lamps, in dark chimneys, one on either side of the axis *OY*. Specular reflection was therefore more in evidence in the lateral portions of the field (*a*, 2 and 4), and still more in evidence in *b*, where the lamps were moved away from *J* and the light was therefore more nearly normal to the surface. The difference between diffuse and specular reflection is naturally greater in proportion from the india ink than from the card.

At *c* to *g*, inclusive, a different system of lighting was used, namely, a diffusing opal glass in the side of a light-tight box containing a 300-watt lamp. This was placed so that the glass was parallel to *OY*, and adjusted in position to give as nearly as possible equal brightness to 2, 3 and 4 as seen by the subject. The various levels of brightness, *c*, *d*, *e*, *f*, *g*, were approximated by placing suitably perforated cardboard 'seives' behind the glass, and adjusted by small changes in the position of the box. Specular reflection is here in evidence under '4,' since this area on the surface *J* was on the same side of the axis *OY* as the lamp-box.

It is to be mentioned here that *b* was used in set *I* only. The relatively low contrast here as compared with that in the other cases did not sufficiently lengthen the threshold time to offset the effect of other circumstances, as will be seen later on. As for the other departures from ideal uniformity in contrast, as far as they may be significant in the results they are probably not greater than in cases where printed or drafted test-objects are used entirely without specification of the relative brightness of the 'black' and 'white.' The difficulties of attaining uniformity are greatly increased by the necessity of securing an extremely wide range of brightness, which can hardly be done without using various modes of illumination.

For the first set of measurements *I*, the scale unit to which test-object and pre- and postexposure patterns were drawn was 3.18 mm. (1/8 inch) which, with double magnification made the effective unit in the image (at *O*) 6.35 mm. At the subject's eye, 6.01 meters away, this unit subtended 3.63′ angle.

For the second set II, the test-object and confusion patterns were drawn to just half this scale, the unit being 1.59 mm. and in the image subtending 1.82′ at the eye of the subject.

The third set III, was run with the same test-object as the second with the omission of the confusion patterns from the pre- and postexposure, so that the image of the test-object appeared immediately out of a blank field of the specified

brightness. This was done for the purpose of making a direct comparison with the results of the earlier work, in which the test-object likewise rose out of an unbroken field, but in which the subject was not required to discriminate form. As the times of exposure became much shorter under these conditions, it was necessary to replace the plane glass in the prism-frame by a narrower one to avoid excessive velocities. This was 4.89 mm. (0.193 inch) wide.

The Subjects

Of the subjects, seven in all, some were attached to the laboratory, and others to other departments at Nela Park. Six of these participated in all three of the experimental sets, and two of them, *A* and *Su* were identical with *A* and *S*, respectively, of the earlier work. The ophthalmologic tests were conducted (except as specified) with or without glasses according as these were or were not worn while under experimentation.

A. A man, age 33, physiological chemist. Vision: R, 20/15 + 3/11; L, 20/20 + 3/8. Wears no glasses. Angle of convergence 26°. Accommodation: R, 8.2 D; L, 8.3 D. Muscles at 6 meters: Esophoria 2$^{\Delta}$, no hyperphoria, prism divergence 5$^{\Delta}$.

D. A woman, age 24, laboratory assistant. Vision without glasses: R, 20/20 + 2/8; L, 20/30 + 4/6. Correction: R, − .75 cyl. ax. 60°, V = 20/15; L, − .75 cyl. ax. 100°, V = 20/20 + 7/8. Glasses worn during experiment. Angle of convergence 50°. Accommodation: R, 10.5 D; L, 11.8 D. Muscles at 6 meters: esophoria 3$^{\Delta}$, no hyperphoria, prism divergence 3$\frac{1}{2}^{\Delta}$.

E. A woman, age 28, work chiefly computing. Vision without glasses: R and L, 20/30 + 5/7. Correction R, + .25 sph.; L, − .25 cyl. ax. 170°; glasses used for close work only and not used during experiment. Angle of convergence 39°. Accommodation: R, 8.5 D; L, 6.5 D. Muscles at 6 meters: esophoria 1/2$^{\Delta}$, no hyperphoria, prism divergence 5$^{\Delta}$.

M. A man, age 24, chiefly laboratory work. Vision: R, 20/30 + 5/7; L, 20/30 + 1/7. Has never worn glasses.

Angle of convergence 44°. Accommodation: R, 13.5 D; L, 13.2 D. Muscles at 6 meters: esophoria 1$^{\Delta}$, no hyperphoria, prism divergence $7\frac{1}{2}^{\Delta}$.

St. A man, age 23, desk and outside work. Vision: R and L, 20/20 + 5/8. Has never worn glasses. Angle of convergence 46°. Accommodation: R, 12.2 D; L, 11.1 D. Muscles at 6 meters: esophoria 3$^{\Delta}$, no hyperphoria, prism divergence 7$^{\Delta}$.

Su. A woman, age 25, research assistant. Vision: R, 20/20 + 7/8; L, 20/20 + 6/8. Wears no glasses. Angle of convergence 39°. Accommodation: R, 10.0 D; L, 11.4 D. Muscles at 6 meters: orthophoria, prism divergence 5$^{\Delta}$.

W. A man, age 24, laboratory and desk work. Vision without glasses: R, 20/40 + 4/6; L, 20/30 + 6/7. Correction: R, − .50 sph. with − .25 cyl. ax. 110°, V = 20/20 + 7/8; L, − .50 sph. with − .12 cyl. ax. 15°, V = 20/20 + 7/8. Glasses worn during the experiment. Angle of convergence 43°. Accommodation: R and L, 11.4 D. Muscles at 6 meters: esophoria 1$^{\Delta}$, no hyperphoria, prism divergence 6$^{\Delta}$.

Procedure

The subject was instructed to fix his eyes on a mark on the screen (*P*, Figs. 1 and 2) 2° to the left of the opening, press the key under his right hand when the 'ready' signal was given, and report at the close of the exposure whether the bars of the test-object were seen in the vertical or the horizontal position. He was given the option of reporting indeterminately if necessary, although this was not encouraged. The reports of the subject were signalled to the experimenter in code by means of a buzzer.

As before, four series were run within an hour's time at one sitting, two of which (*L*) were run with extended surroundings (47 × 48° in the visual field) of the same brightness as the test-object ground, and two (*D*) with the bright field of restricted extent (5.8 × 5.2°). These four were run for each brightness in the orders *LDDL* and *DLLD*, alternately.

The method of serial groups was used. The exposures were made in groups of ten, five with the test-object in the

vertical position, five in the horizontal, in predetermined irregular order. A time of exposure was found by trial, and later with the help of previous experience, of sufficient length for the subject to *score* 8/10 or better. The time was then shortened by one step on the stroboscope (about 20 per cent.) and another group of ten exposures made, and so on, until the time became so short that the score for the group was 2/10 or less. This concluded one series. The average number of groups in one series was probably not less than 5. As there are 1920 series represented in the three sets of results, the total number of exposures and reactions therefore is close to 100,000.

The score for each experimental group was simply the number of right answers minus the number of wrong, the base being the whole number, 10. The indeterminate answers were counted as neither right nor wrong, but only as completing the total of 10 for the base. Thus the experimental series yielded a series of scores corresponding to a series of times, and the time-threshold was computed from these, corresponding to the duration of exposure at which a score of 5/10 was passed. This was done by linear interpolation as follows: (*a*) reading the scores in the direction given, from longer to shorter times, a linear interpolation was made between the last score greater than 5/10 and the first one less than this; (*b*) similarly reading the series of scores in the reverse direction, interpolating for the 5/10 point between the last one less and the first one greater than this. Usually *a* and *b* coincided, otherwise their arithmetic mean was used.

In case a score of 5/10 was encountered in the computation, it was assigned a weight in taking the mean of *a* and *b* as follows: when the two adjacent scores were greater and less than 5/10 respectively, the weight was unity; otherwise it was 1/2. The latter case included three possibilities: both adjacent scores greater, both less, and one only equal to 5/10.

Under each brightness and for each subject there were 10 series run (and consequently 10 threshold measurements made) with extended bright surroundings (*L*), and 10 with restricted bright surroundings (*D*). It was desirable to make

an estimate of the differences in the results due to differences in place in the course of experimentation, and to make the results intercomparable for this purpose each ten thresholds for identical conditions were averaged, and then each one of the ten was divided by this average. The quotients so obtained are here designated as *relative* values. Obviously the mean of each such group of relative values was unity, irrespective of the conditions or of the absolute values.

By selecting all the relative values for the 1st, 2d, 3d, 4th series in the day, and averaging each of the four groups, the averages will show whether the place of the series in the day is of significant effect; and by similarly averaging the relative results in groups according to the day of experimentation in the course, a progressive time effect could be shown where present. Finally, it was possible from all of these relative values to compute a general relative mean variation or standard deviation for each subject, as a basis for the appraisal of his work and the establishment of a weight for his results in the final average.

The Results

The results of these computations are given in Table I. By Pearson's method, the relative values for the day were correlated with the ordinal numbers of the days of experimentation. The characteristic equation derived from this correlation gave the coefficient of daily decrease (9th column) of the threshold time, and the standard deviation of the threshold from this line of decrease (3d column). The 4th to 7th columns give the average relative values for the 1st, 2d, 3d, 4th series in the day and the 8th column gives the probable error of these averages, computed from the standard deviation (column 3) and the number of series involved in each average.

These values were used in applying corrections to the averages of ten series each (*L* or *D*, each brightness and each subject) given in Table II. Two factors were computed for each group of 10 values: (*a*) the mean of the values under 1, 2, 3, 4, Table I., each taken as many times as it was repre-

TABLE I

RELATIVE VARIABILITY OF THE THRESHOLD TIMES

N—Total number of series involved in the results.

$\sigma_{1.2}$—Relative standard deviation from closest fitting straight line of daily decrease.

1—Mean relative threshold time for all series run first in the day.

2, 3, 4—Similarly, second, third and fourth in the day.

$\pm E$—Probable error of averages under 1, 2, 3 and 4.

Mean daily gain—Derived from the equation of the closest fitting straight line of daily decrease of the relative threshold.

Mean $2\frac{L-D}{L+D}$—Mean excess of threshold time under extended bright surroundings over restricted, relative to the mean of the two.

E (last column)—Probable error of the preceding.

Subj.	*N*	$\sigma_{1.2}$ Rel.	Order in Day				$\pm E$	Mean Daily Gain	Mean $2\frac{L-D}{L+D}$	*E*
			1	2	3	4				
I. *Visual Angle 3.63′, with Confusion Patterns*										
A.....	140	.128	.996	1.018	.960	1.026	.015	.014	+.077	±.015
D.....	140	.203	1.032	1.016	.979	.972	.023	.009	+.019	±.024
E.....	140	.146	.958	1.014	.986	1.042	.017	.014	+.017	±.018
M.....	140	.171	.974	1.008	.999	1.018	.020	.007	+.048	±.021
St.....	140	.248	1.069	1.052	.952	.926	.029	.016	+.046	±.030
Su.....	140	.232	.946	.999	1.043	1.011	.027	.012	+.024	±.028
W.....	140	.227	1.021	.972	1.023	.983	.026	.011	+.004	±.027
II. *Visual Angle 1.82′, with Confusion Patterns*										
A.....	80	.147	1.018	1.038	1.030	.913	.023	.004	−.048	±.023
D.....	60	.250	.933	.990	1.016	1.061	.045	.010	−.222	±.046
E.....	80	.171	1.086	.987	.982	.945	.026	.010	+.024	±.027
M.....	80	.184	1.061	1.011	.964	.963	.028	.005	−.183	±.029
St.....	60	.305	.885	.900	1.059	1.157	.055	.000	−.254	±.056
Su.....	80	.215	.958	1.038	1.015	.988	.033	.008	−.062	±.034
III. *Visual Angle 1.82′, without Confusion Patterns*										
A.....	80	.138	.953	.978	1.053	1.016	.021	.000	−.023	±.022
D.....	80	.229	.946	.981	1.016	1.056	.035	.007	−.092	±.036
E.....	80	.190	1.062	1.025	.970	.943	.029	.011	+.101	±.030
M.....	80	.149	1.023	1.028	.973	.976	.023	.004	−.255	±.024
St.....	60	.255	.968	.909	1.054	1.068	.046	.006	−.175	±.047
Su.....	80	.168	1.018	.989	.997	.996	.026	.001	−.127	±.027

TABLE II

MEAN THRESHOLD TIMES.

The values given are each the mean of ten measurements obtained by interpolation within each of ten series. The reciprocals of these values are plotted in Figs. 4 to 10 inclusive.

Rel. E_{10}—Relative probable error of the averages.

p—Weights assigned the several subjects for computing the geometric mean values given in Table III. and plotted as reciprocals in Fig. 11.

Subject	*a*		*b*		*c*		*d*		*e*		*f*		*g*		Rel. E_{10}	p
	L	*D*	*L*	*D*	*L*	*D*	*L*	*D*	*L*	*D*	*L*	*D*	*L*	*D*		
	I. Visual Angle 3.63′, with Confusion Patterns															
	89.1 ml.		49.0 ml.		28.8 ml.		12.0 ml.		4.79 ml.		1.95 ml.		0.87 ml.			
A	12.3	10.0	11.8	10.6	11.0	10.4	11.3	11.5	11.9	11.2	14.7	13.9	16.9	16.0	.029	.29
D	13.3	14.1	14.2	15.5	15.1	16.3	17.2	16.6	25.1	19.9	22.6	22.6	28.0	25.7	.046	.11
E	17.8	18.1	15.3	16.9	13.8	13.6	16.1	16.4	18.3	17.7	22.8	21.2	26.2	22.7	.033	20
M	12.1	9.7	9.4	7.6	8.8	8.1	9.2	10.4	10.1	10.2	13.5	14.4	18.2	17.7	.038	.20
St	20.4	21.9	18.1	20.0	22.3	20.6	19.7	19.3	20.3	17.4	28.6	20.9	30.5	32.8	.056	.08
Su	15.2	15.0	14.1	13.8	14.1	14.6	15.8	15.8	14.3	13.5	18.8	17.1	21.9	21.5	.052	.14
W	10.4	11.7	10.1	10.0	9.0	9.8	13.2	12.4	11.8	12.1	14.4	13.5	20.1	17.5	.051	—

TABLE II (*Continued*)

	II. Visual Angle 1.82′, with Confusion Patterns											
	91.2 ml.			12.6 ml.		5.01 ml.			0.91 ml.			
A	13.6	12.7		14.7	17.6	17.1	20.2		46.9	43.0	.033	.29
D	34.3	45.0		46.9	54.7	68.2	87.1				.056	.11
E	19.3	17.8		21.4	21.0	26.8	26.9		61.9	62.1	.038	.20
M	14.0	17.5		17.8	21.6	27.0	32.6		93.7	106.3	.041	.20
St	49.8	56.8		67.2	103.4	116.8	143.5				.069	.08
Su	24.6	25.9		27.3	33.2	34.7	38.0		81.8	74.8	.048	.14

	III. Visual Angle 1.82′, without Confusion Patterns											
	91.2 ml.			12.0 ml.		5.01 ml.		1.86 ml.		0.93 ml.			
A	3.8	4.5		6.4	6.8	9.3	9.6			27.8	23.0	.031	.29
D	17.2	18.3		30.6	34.7	46.1	50.5	61.5	67.2			.051	.11
E	4.6	4.3		8.0	7.0	11.5	11.4			35.9	30.1	.043	.20
M	5.4	6.8		10.5	15.2	15.7	21.7			52.6	58.1	.033	.20
St	17.2	18.4		40.3	54.2	51.4	60.3					.057	.08
Su	8.9	8.7		13.4	15.3	17.7	21.0			47.4	59.4	.038	.14

sented in the group, and (*b*) a factor derived from the mean daily decrease, corresponding to the relative value for the mean of the ordinal numbers of the days represented in the group, according to the characteristic equation. The product of *a* and *b* then represented the relative value for the average of the ten to be expected from their place in the set. The

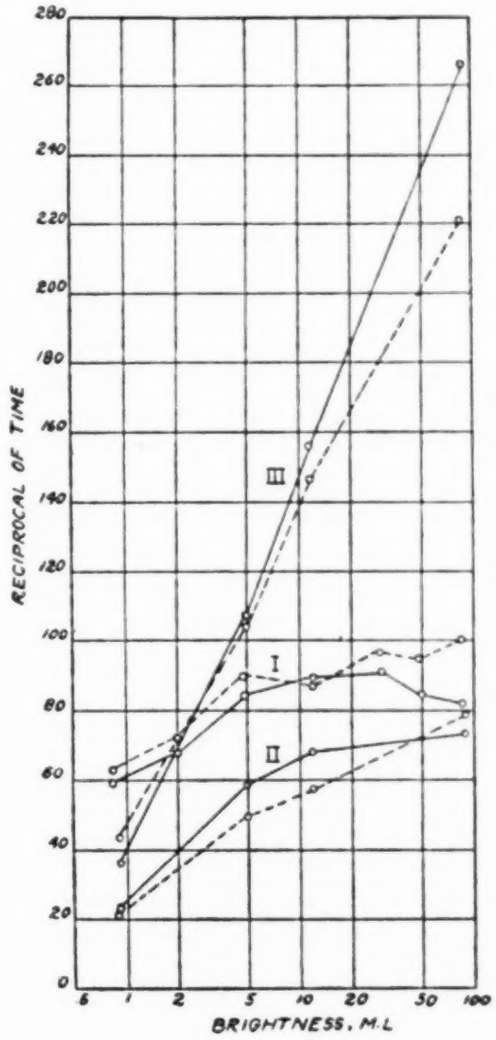


FIG. 4. Subject *A*

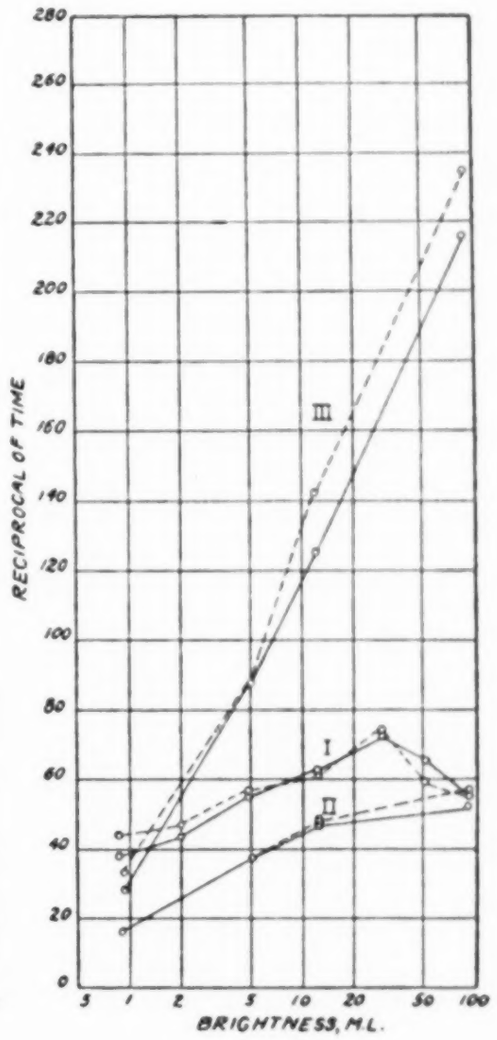


FIG. 5. Subject *E*

FIGS. 4 to 10, inclusive. Each point indicated by a circle is the average of 10 results. Brightness, stated numerically as millilamberts, is plotted logarithmically.

I. Test-object subtending 3.63 minutes. Confusion pre- and postexposure patterns.

II. The same, dimensions reduced to 1.82 minutes.

III. The same as II., pre- and postexposure patterns removed.

Solid lines ———— extended bright surroundings, 47 × 48°.

Broken lines - - - - - - - - restricted bright surroundings, 5.8 × 5.2°.

average value for the ten was therefore divided by the product *ab* in order to reduce it relatively to the value for the mean place in the course. Each average appearing in Table II. has been so corrected, and the reciprocals of these corrected values for the several subjects are plotted in Figs. 4 to 10.

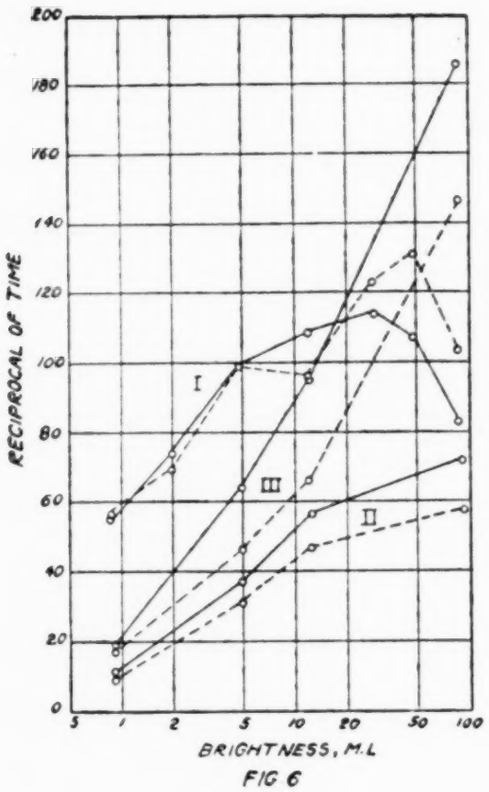


FIG 6

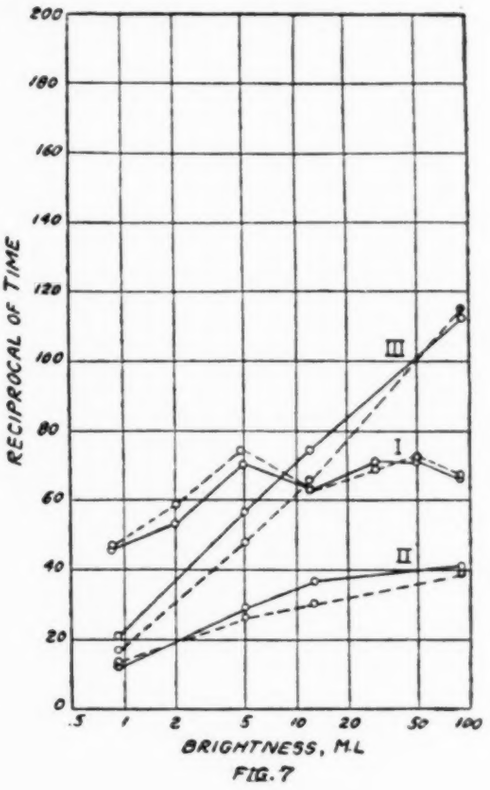
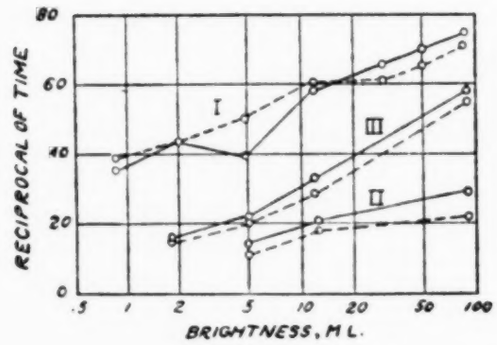


FIG. 7



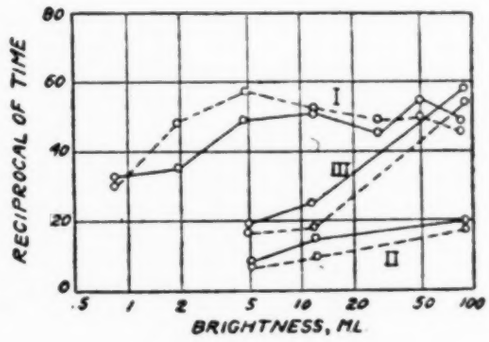


FIG. 6. Subject *M*
FIG. 8. Subject *D*

FIG. 7. Subject *Su*
FIG. 9. Subject *St*

The magnitudes of the corrections so applied were: for *a*, in 17 out of the total of 19 cases[3] in which it was applied,

[3] Nineteen cases as follows: Set I., 7 subjects; Sets II. and III., 6 subjects each. The correction was uniform for each case (1 ± the value stated), except in the instance noted.

from zero to ± .004 of the values corrected, and ± .007 in the extreme cases, except for one pair of averages where it

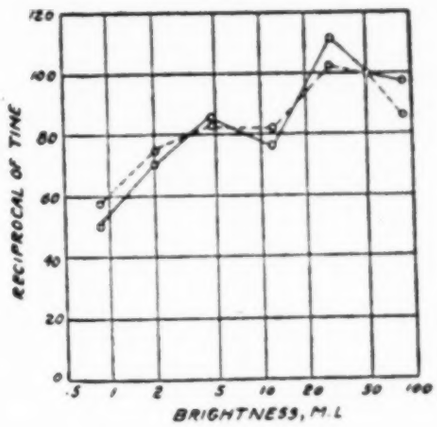


FIG. 10. Subject *W*

was as great as ± .016. Here an error occurred in the order of experimentation, and the series (1, 2, 3, 4) were less evenly divided in the two groups of ten (*L* and *D*) than planned.

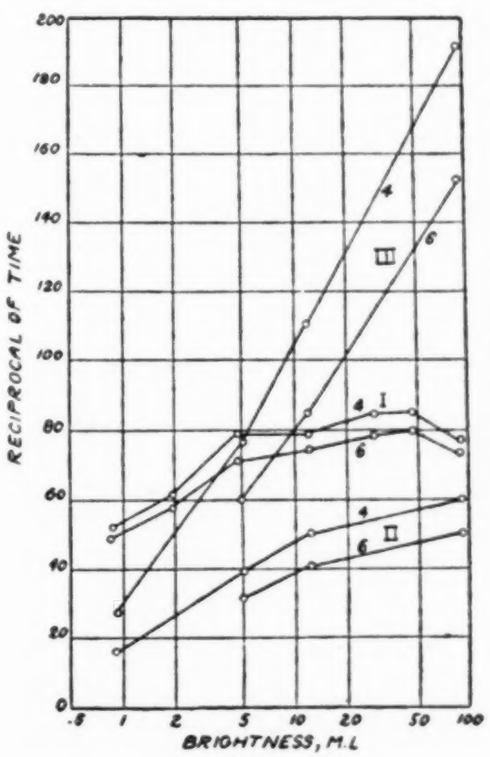


FIG. 11.

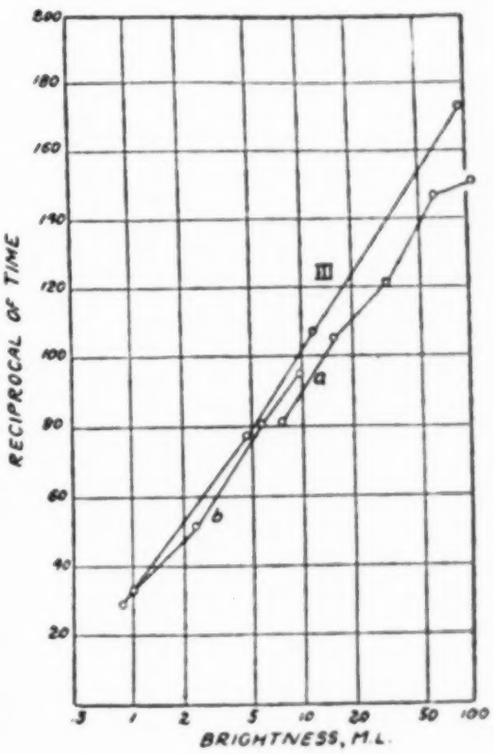


FIG. 12.

FIG. 11. Weighted geometric mean values: 4, for Subjects *A*, *E*, *M* and *Su*, 6, for Subjects *A*, *E*, *M*, *Su*, *D* and *St*.

FIG. 12. Comparison of results of 'dot' test of prior work, *a*, *b*, (not requiring vision of form) with set III. of the present work. Two subjects, *A* and *Su*, in both cases. Probable errors: *a*, *b*, .014; III. .017 of the values plotted.

For b the mean correction (94 cases)[4] was $\pm$ .0135 of the values corrected, the extremes about $\pm$ .09.

Further, in Table II., under 'Rel. E_{10}' is given the relative probable error computed from the standard deviations of Table I. for the average of ten. For intercomparison of sets I., II. and III., (Fig. 11) a uniform set of weights was used in averaging the individual results. These weights are given under 'p,' Table II., and are computed for the respective individuals as the sum of the inverse squares of his three relative standard deviations in the three sets. The weighted mean times are given in Table III.

Table III

Weighted Mean Times

The three sets of results I., II. and III. are as described in the text and indicated in Tables I. and II.

4—Complete results, means of subjects *A*, *E*, *M* and *Su*.

6—Means of six subjects, including the above, and *D* and *St*.

Set	No. of Subj.	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*E* Rel.
		89.1 ml.	49.0 ml.	28.8 ml.	12.0 ml.	4.79 ml.	1.95 ml.	0.87 ml.	
I.....	4	13.1	11.8	11.9	12.6	12.8	16.4	19.4	±.018
	6	13.6	12.6	12.8	13.5	14.0	17.5	20.8	±.016
		91.2 ml.			12.6 ml.	5.01 ml.		0.91 ml.	
II.....	4	16.7			20.0	25.4		64.6	±.019
	6	20.0			24.7	32.6		—	±.018
		91.2 ml.			12.0 ml.	5.01 ml.		0.93 ml.	
III.....	4	5.2			9.1	13.1		36.7	±.018
	6	6.6			11.9	16.9		—	±.016

Fig. 12 has been added to show the relation between the results of the former work and those of set III. of the present. Two identical subjects acted in both of these sets. The curves *a*, *b* indicate the result for these two when the dot test was used, that is, when the mere presence or absence of the test-object had to be reported, whereas the curve III. is derived from their results embodied in the curves of the same designation in Figs. 4 and 7, where the form of the

[4] Ninety-four pairs of averages.

object had to be reported. Both of these sets were taken without the use of the pre- and postexposure patterns, the test-object rising out of an unbroken field in each case.

Discussion

The similarity of the two curves shown in Fig. 12 is quite striking as compared with the characteristic differences between the curves I., II. and III. in Figs. 4 and 7, and it is only reasonable to suppose that a much closer agreement might have been reached if the results of *a* and *b* had been taken within one set, thus equalizing the progressive time effect; and if either a somewhat larger object had been used in the case of *a* and *b* or a somewhat smaller one in III.

It will be noticed that his relation, between the reciprocal of the threshold time and the logarithm of the brightness is, in the average, nearly if not quite a linear one within the limits of brightness tried for these two cases which have in common the fact that the test-object appeared by itself on a blank field. A straight line on the plot would have the equation:

$$\frac{1}{t} = k \log \frac{B}{B_0},$$

where t is the time, B the brightness, B_0 the brightness at which the time becomes infinite, and k is a constant. This fact determined the choice of the method of plotting, and the departure of the results from this sort of relation, especially under conditions I. and II., where pre- and postexposure patterns were used, is evident from a glance at Fig. 11.

Figs. 4 to 10 show the extent to which, under condition III., the individual agrees with the logarithmic relation, as well as the various relations that appear in different individuals between the three conditions. Aside from quantitative differences which are by no means small, inspection of the plots reveals other individual differences of importance. The removal of the pre- and postexposure patterns results invariably in a shortening of the threshold time (increase of 'speed'), accompanied by a change of curvature between the two curves typically represented in Fig. 11, curves II. and III.

Doubling the dimensions of the test-object and confusion patterns results also in a shortening of the time, as might well be expected. But the change in the course of the results with increasing brightness is totally different from that which takes place when the test-object remains of the same size and the confusion patterns are removed. In the latter case, the results typically approach the straight-line relation. In the former, the change may be stated in this way: With the smaller test-object (II.), each increase in the brightness by a given factor results in a smaller increase in the speed, no maximum occurring, however, at or below the highest brightness used, 90 ml. With the larger object (I.), a maximum is reached in the typical case in the neighborhood of 20 to 50 ml.

For the individuals, the comparative results of these two changes are interestingly various. Curve III. lies chiefly above curve I. for subjects *A* and *E*, the two intersect at about mid-range (10 ml.) for *Su*, above this for *M* and *St*, and for *D*, III. lies wholly below I. within the range of brightness used. The first thought would be that those subjects showing lower visual acuity by the opthalmologic test-card would naturally respond in a greater degree to increase in the dimensions of the test-object, in spite of the confusion patterns, which may be expected to retard vision in a wholly different way. On this hypothesis, there should be a significant correlation between the tendency to lower threshold time under condition III., as compared with I., on the one hand, and visual acuity on the other. The rank-difference method yields a coefficient of correlation equal to -0.19 with a probable error ± 0.27, which is insignificant over and above the fact that it is contrary to the hypothesis in sign. We may, therefore, conclude that visual acuity has little or nothing to do with the individual variation just discussed.

Obviously, the divergence just mentioned, together with other individual differences which will appear from the study of Figs. 4 to 10, should make one cautious in accepting average values, as plotted in Fig. 11, as representing any 'law' of vision. It was nevertheless desirable to construct some general expression of the course of the threshold time

as a function of brightness for the three modes of vision; and the average values which appear in Fig. 11 will perhaps have to be looked upon as those which might have been obtained from a 'typical' subject.

In weighting the individual values to get these averages, this aim was kept in mind. The geometric mean was used, in order that a subject with a large threshold and a small proportionate variation with a given change in conditions might not outweigh another with a small threshold and large proportionate variation. The weights were assigned, to each individual inversely as the square of his relative standard deviation. If we suppose that *A* has a relative standard deviation twice that of *B*, it follows that for equal precision *A*'s average should be derived from four times as many measurements as *B*'s. Since, however, we have the same number of measurements on each, *A*'s average would represent only one fourth as many measurements of standard or unit weight as *B*'s. Hence the weights assigned in this hypothetical case would be as 1 to 4 for *A* and *B* respectively; otherwise *A*'s accidental variations would unduly outweigh *B*'s systematic variations with brightness.

It is to be added, that in taking the averages of the individual results, plotted in Fig. 11, the average was regarded as a function of the individual values, and not as a mean in the statistical sense. That is to say, the differences between individuals are clearly systematic and are to be regarded as such, without being allowed to enter in such a way as to diminish the precision of the average. The weights enter as multipliers of the logarithms of the respective terms, the weighted average logarithm is the logarithm of the average, and the relative probable error of the average, given in the last column, Table III., is:

$$E = \frac{1}{\Sigma p} \sqrt{\Sigma E_1^2 p^2},$$

where E_1 is the relative probable error of any individual value, and p is the corresponding weight.

Since, in general, those subjects with the largest relative

standard deviations have the lowest values for speed, it follows that the weights used would yield an average indicating higher speed than the uniformly weighted average for the same group. In industrial practice, the tendency would be toward the elimination of the relatively slow individuals in the course of events, in just the same sense as this method of weighting reduces the extent to which their results participate in the average. Therefore, while the values plotted in Fig. 11 are perhaps less representative physiologically, they form a scheme more nearly applicable to practice than would a set of uniformly weighted averages. In any case they are not to be accepted without a careful study of the individual values of Table II. plotted in Figs. 4 to 10, from which they are derived.

The discussion has so far been limited to the effect of the brightness level upon the threshold time for discrimination, within the three different modes of vision corresponding to the three sets of results. It has been mentioned that parallel sets of measurements were made throughout, with the bright field of greater and of less extent: *L*, 47 × 48° and *D*, 5.8 × 5.2°. The results in Table III. and Fig. 11 have been derived from the means of the two parallel values.

Something is to be said of the difference between these two. Examination of Figs. 4 to 10 will indicate that the parallel values, in general, run much the same course, with quantitative differences which in some cases are, in fact, greater than may be ascribed to chance variation. The magnitude of these differences and their significance will appear from the last two columns of Table I. For each brightness the difference between the two threshold times ($L - D$) was computed as a fraction of their average, and in the next to the last column of the table the mean of these relative differences, for the subject within the set, is given, followed (in the last column) by its probable error.

From these, the following will appear: with the large test-object (I.) the differences are positive without exception (*L*-time greater than *D*-time), but not of significant magnitude except in the case of *A*, whose difference is slightly more than

five times its probable error. It is quite otherwise in II. and III. Except for subject *E*, the differences are all negative. A longer time is required with the restricted bright field, in some cases to a degree that is very remote from chance. The positive difference in the case of subject *E* might be said to be barely significant in set III. only—where it is slightly over three times its probable error.

It is to be borne in mind that these are in the first place relative differences, and that each is the mean for all brightnesses. In the case of any individual an idea of their constancy may be gained from a study of his plot (Figs. 4 to 10).

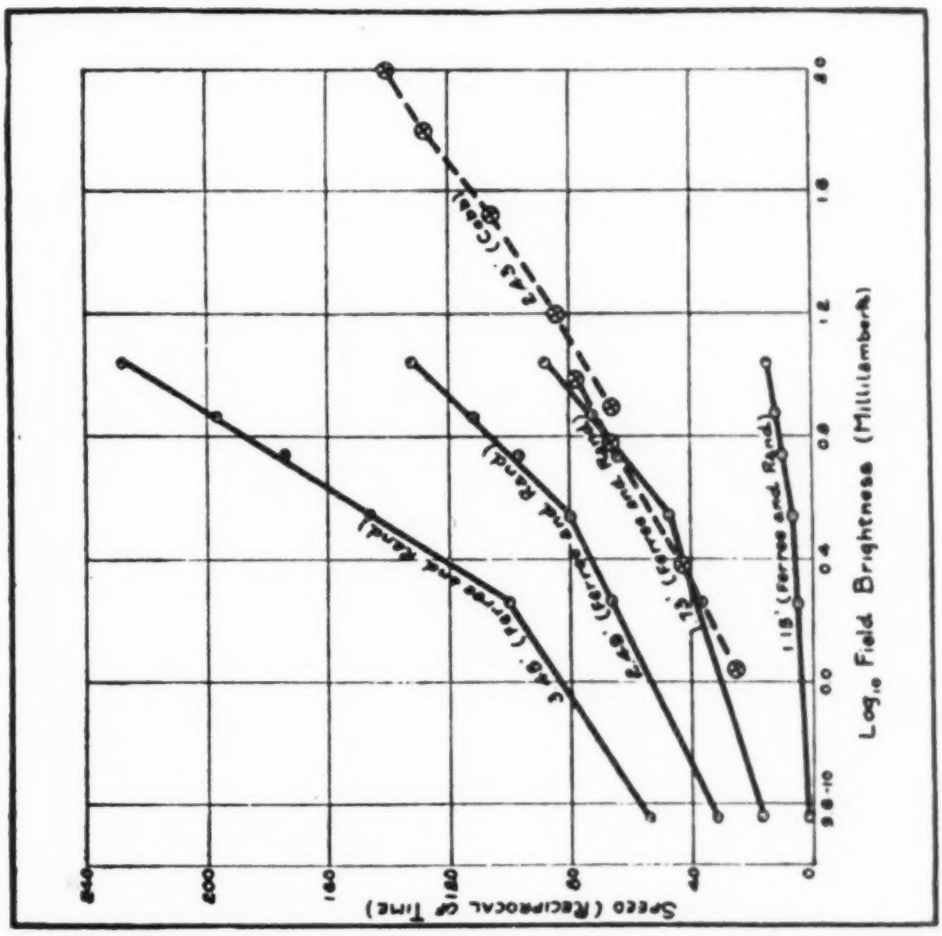


FIG. 13. Plot presented by Ferree[7] comparing results of Ferree and Rand with the present work. The writer's 'dot' test was here selected for comparison regardless of the fact that it does not require discrimination of form.

It will be of interest here to call attention to a relevant piece of work of recent date by Ferree and Rand. Following

the presentation in outline of the results detailed in this paper, one of these authors communicated a discussion to the Illuminating Engineering Society, containing a graphic presentation of their results (Fig. 13), and drawing a comparison with one set considered in the present paper; which was, incidentally, not in fact the one to be selected for such comparison nor even by Dr. Ferree's own statement the least unsuitable for such purpose.

Before beginning a comparison of the two pieces of work, a word may be said of the results of Ferree and Rand. They are measurements of the least time of exposure of a test-object, the Landolt broken ring, required for the subject to report correctly the location of the break in five out of the eight different positions in which it was presented. Investigation of the pre- and postexposure factor was not attempted. Four sizes of test-object were used, from 1.15 to 3.45 minutes visual angle, and six levels of illumination, from 0.4 to 12 foot-candles. The writer has not been able to find that the numerical results have been published at all. They have appeared graphically, plotted against foot-candles illumination,[5, 6] and again, in the discussion referred to,[7] against the logarithm of the brightness in millilamberts. Numerical values can only be arrived at by scaling from the plots. From these scaled values it appears that while the three presentations show too many points of identity to admit of their being entirely different sets of data, there are nevertheless substantial differences which may, in part, be set down as errors in plotting. Thus it is with certain unequivocal differences between Fig. 3*a*,[5] p. 283 and Fig. 1,[6] p. 76.

In the discussion referred to [7] the data were plotted against the logarithm of the brightness 'in order to be able to compare them with Dr. Cobb's for the black dot as the test-object' (*loc. cit.*,[7] p. 169) and it was discovered incidentally that 'our results plotted against log. brightness show two arms of different slope' (*loc. cit.*,[7] p. 170). It is interesting to

[5] Ferree and Rand, *Trans. Am. Ophth. Soc.*, 19, 1921, p. 283, Fig. 3*a*.

[6] Ferree and Rand, *Trans. Illum. Eng. Soc.*, XVII., 1922, pp. 75–76.

[7] *Trans. Illum. Eng. Soc.*, XIX., 1924, Fig. on p. 170. See also preceding paper, pp. 150–163; and accompanying discussion by C. E. Ferree, pp. 167–174.

note in this connection: first, that in the curve for the 1.73′ test-object, at the break (log. ml. = 0.54) the 'speed' plotted is lower by 7 points than that of the two earlier presentations (47 instead of 54), while the values next on the curve differ from the earlier ones by 2.6 and 1 point respectively (36.6 instead of 34, and 64 instead of 65); and second, that the values in the curve for the 1.15′ test-object, where they are large enough to admit of tolerable comparison from the plots at all, are all lower than those in the earlier plots. Since the earlier plots agree with each other very closely in these values, they have been plotted separately here in Fig. 15, for comparison with the data presented in the discussion, which have been carefully re-plotted in Fig. 14,

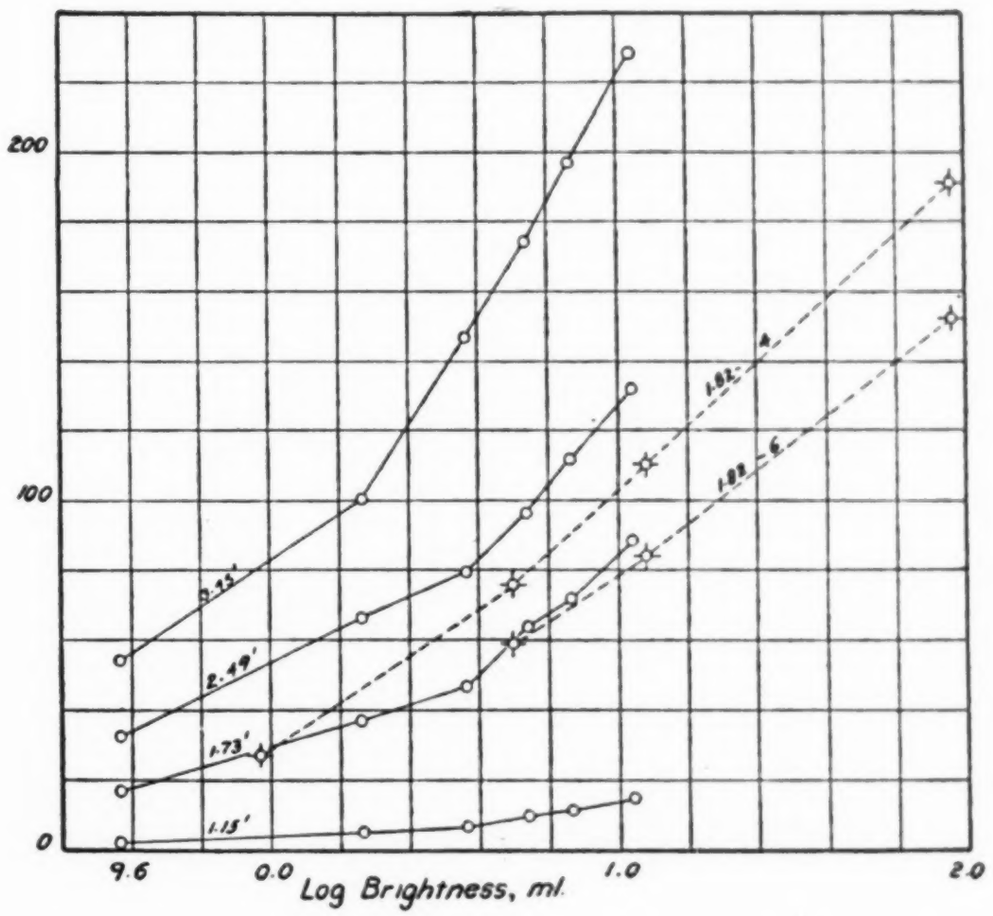


FIG. 14. The results of Ferree and Rand (solid lines), replotted from Fig. 13; compared with the results of set III. (Fig. 11) of the present work (dotted lines), requiring form discrimination, visual angle 1.82′, no confusion pre- and postexposure patterns, six and four subjects respectively as indicated.

with the omission of the distracting heavy lines drawn in to emphasize the break in the slope discovered after plotting the original results against the logarithm of the brightness for comparison with the results of the writer.

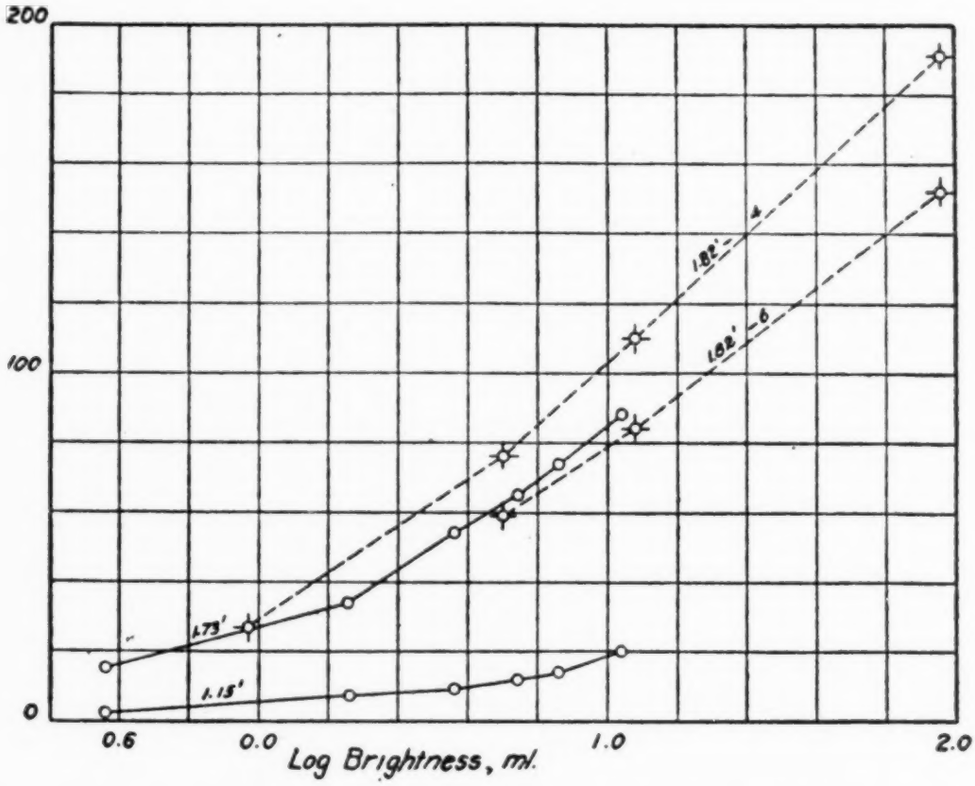


FIG. 15. The results of Ferree and Rand as previously presented[5, 6] for 1.15 and 1.73′ visual angle only; otherwise the same as Fig. 14

Concerning this change of slope, the evidence certainly does not warrant the positive statement: 'Our results plotted against log. brightness show two arms of different slope. In each arm the results seem to follow consistently the log. of brightness' (*loc. cit.*,[7] p. 170). This assertion is especially interesting, since the beginning and the end of Dr. Ferree's discussion are to deplore the attempt 'at this time to formulate a law expressing the relation of speed of vision to brightness of working surface' (*loc. cit.*,[7] p. 167, and see further, p. 173).

The most that may be said is that between the limits 1 and 11 ml. brightness, where alone comparison is possible, the curvature shown is greater in the results of Ferree and Rand, whichever set of their data we select, than it is in the

results of the writer. In the latter case the curvature is not so prominent as to preclude qualified reference to the formula $1/t = k \log (B/Bo)$, or a verbal statement to that effect, as a concise approximate statement of the results that were obtained between the stated limits of brightness. This equation, by the way, does not appear in the paper,[7] but is dragged into the discussion and into the Transactions of the Illuminating Engineering Society from another source [1] by Dr. Ferree, at the immediate risk of realizing his worst fears: 'The formulation and acceptance of such a law prematurely can only do harm. Once a law is formulated the poverty of the evidence on which it is based is forgotten and the law soon takes the place of experimental determination' (*loc. cit.*,[5] p. 173).

With individual values as diverse as they are, it is not difficult to explain absolute differences in the values found for the time threshold or the 'speed.' Especially is this true when, in addition, the measurements are made by different experimenters using different methods of experimenting, with different forms of test-object which are not strictly comparable in terms of any single angular dimension, testing different areas of the retina, with undoubtedly different distributions of light and shade in the visual field outside the region within which the test-object appears; and lastly, with different groups of subjects selected with different considerations in mind. Further, the method of averaging the values will make a difference. With individual differences as large as they are, the average of the individual speeds will be materially larger than the speed computed from the average of the individual times. The writer has avoided this dilemma by using the geometric mean, which yields an identical result either way.

The point to be explained is thus the difference in curvature in that region (1 to 11 ml.) where comparison of the two sets of results of about equal magnitude is possible. The writer is willing to waive the opportunity for explaining this, principally on the grounds set forth in the last paragraph. But incidentally, in enumerating reasons for the difference, it will be well to call attention to one difference in experimental

method which Dr. Ferree has omitted to mention. In an early report on their work, Ferree and Rand describe the method used by them for controlling the time of the stimulus: 'Exposures were made by means of a tachistoscope somewhat similar to that devised by us for the Air Service of the U. S. Army, furnished with only one set of exposure discs rotating in front of and as close as possible to, the test-object. On the front surface of these discs in line with the observer's eye and the test-object was placed a fixation cross in order that the exposure might begin with the eye in approximate adjustment for the test-object' (*loc. cit.*,[6] p. 75). The writer is personally acquainted with the army tachistoscope, having had first-hand experience with it while in the Air Service. The shaft which carries the discs is driven by a long, light rod at right angles to it, weighted and counterweighted to secure the chosen movement and speed of the discs. When released, the fixation cross on the disc thus begins to move before the subject's eyes, at first slowly, just before the opening in the disc exposes the test-object. To what extent this disturbs fixation at the critical moment is an open question. *A priori* this possibility of a time loss is a feature strenuously to be avoided, especially at the instant in advance of the exposure, and especially also, when the total time is as short as some of these under discussion. In planning the work here reported one of the principal considerations was the avoidance of the possibility of an error from this cause. Nothing whatever has been said by Ferree and Rand, or by either of them, to indicate that such a possibility has occurred to them at all. Even supposing the error to be a constant time, it becomes a factor of increasing importance in the extent to which it will distort the plot as the actual threshold time of exposure becomes smaller, and the sum of the two is converted into 'speed' by taking its reciprocal.

Summary

1. In any measurement of the least effective time of stimulation of the retina, a factor of primary importance is the character of the immediately preceding and the immediately following stimulation.

2. The threshold time for a stimulus arising out of an unbroken field of brightness equal to that of its own background follows almost the same law with respect to that brightness, whether the subject reacts simply to the presence or abscence of the stimulus, or reacts differentially to a detail of its form.

3. The relation in this case is, that the reciprocal of the threshold time increases equally with equal increases in the logarithm of the brightness. This is approximately established between the limits 0.9 and 90 millilamberts.

4. The effect of introducing patterns, immediately preceding and following the test stimulus in time, is to increase the threshold time of exposure. The increase is somewhat more at low than at high brightness. This addition to the time is such, however, that the reciprocal of the time, in consequence, increases less and less with each increment in the logarithm of the brightness.

5. The effect of changing the dimensions of the test-object and pre- and postexposure patterns by an equal factor throughout is expressed by the statement that increase in the size of the stimuli tends to reduce the time to a minimum. With a larger object (3.63 minutes) the minimum appears to have been reached below 90 ml. (within 20 to 50 ml. in the average). With a smaller object (1.82 minutes), on the other hand, no minimum was reached at the highest brightness used, 90 ml.

6. Individuals present wide differences, not only quantitatively as differences in the threshold times under like conditions, but qualitatively in their response to the various experimental factors. Thus, using the results obtained with the smaller test-object and confusion patterns (II.) for comparison: doubling the dimensions of these has the effect of shortening the threshold time (I.); and removal of the confusion patterns also shortens the threshold time (III.). But with two out of six subjects the time under condition III. is shorter than under I. except at the very lowest brightness (0.9 ml.); while on the other hand one subject requires more time under III. even at the highest brightness (90 ml.); while intermediate relations in this respect appear in the others.

7. These individual differences do not correlate with visual acuity as measured with the letter chart.

8. Average values may be considered only relatively, as with reference to changes in threshold time or 'speed' with changes in brightness. While such average values may be looked upon as representing the performance of a supposably 'typical' subject, the wide individual differences, qualitative as well as quantitative, are of no less importance than any other feature of the results.

THE CARDIAC, RESPIRATORY, AND ELECTRICAL PHENOMENA INVOLVED IN THE EMOTION OF FEAR[1]

BY W. E. BLATZ

Introduction

This study is concerned with the cardiac, respiratory and electrical changes which occur during and subsequent to the arousal of the emotion of fear.

This emotion was aroused by precipitating the subject backwards unexpectedly while he was seated in a chair. The mechanical arrangement for producing this situation was as follows (see diagram I). A rigid framework was attached solidly to ceiling and floor. Within this shell a specially constructed chair with a high back was swung on an axle (*F*) running through the front of the seat. The chair was held firmly in an upright position by a steel hook (*A*) catching the top of the back. The hook supporting the chair could be released by the experimenter from an adjoining room by means of a handle which was rigidly attached to this hook. The weight of the subject was sufficient to cause the chair, when released, to topple precipitously backwards. To avoid injury and jarring a strong door check (*D*) was attached to the back of the chair at *H*. The fall was thus gradually checked after the subject had fallen freely for about 60 degrees. The chair finally came to rest against the stop *B*, taking the position indicated by the dotted line. To avoid confusion the framework has not been sketched in the diagram.

All of the recording apparatus was located in a room at some distance from that in which the chair was placed. The instrument used for registering the cardiac and electrical changes was a standard Hindle electrocardiograph.[2] This

[1] From the Psychology Laboratory of the University of Chicago.

[2] This instrument was borrowed from the Department of Physiological Chemistry of the University of Chicago, whose coöperation is acknowledged with thanks. For a detailed description of the apparatus and its uses see Wiggers, 'Circulation in Health and Disease,' 1923, pp. 251, ff.

apparatus consists essentially of a delicately adjusted string-galvanometer and a photographic device which records alterations in the position of the string due to changes in the electromotive force of the subject. Since muscular activity

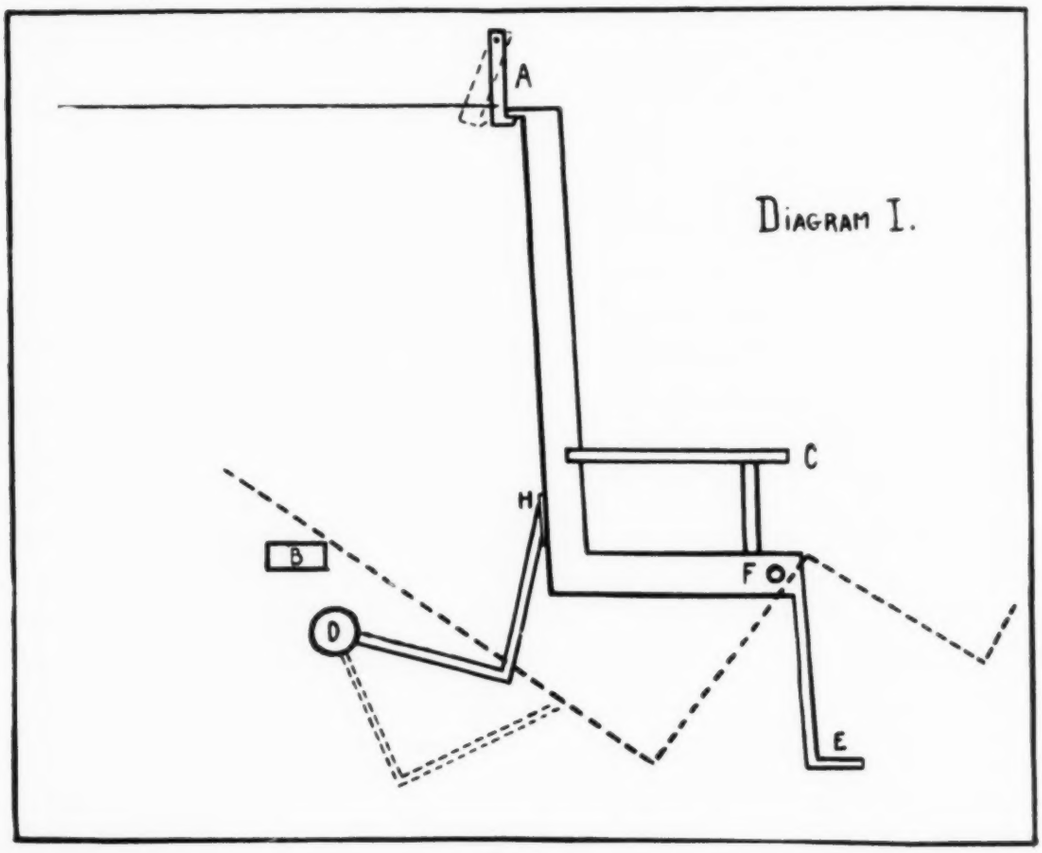


FIG. 1

is accompanied by electrical changes, each heart beat is recorded by this instrument. Any other electrical change is, of course, registered as well.

The two electrodes,[2] which connect the subject with the electrocardiograph, were cut from zinc plates about 1 mm. thick and 5 cm. in diameter. Copper wires were soldered to each and connected with the resistance box. A place on the palmar surface of the right fore-arm about 5 cm. proximal to the wrist joint was selected for the application of one electrode. The other electrode was applied either to a similar place on the left forearm or upon a spot on the outer surface

[2] Acknowledgment is gratefully made to Dr. K. Richter for suggesting the use of the "dry" electrodes.

of the left leg just proximal to the ankle. The electrodes were covered with a paste, made of a saturated solution of zinc-sulphate and kaolin, and were then bound to the limb with a lint bandage. This bandage was employed to prevent movement of the electrodes during the fall.

For recording the respiratory changes an electrical pneumograph [3] was employed (see *A*, diagram 2). The connections were such that, during inspiration, this instrument activated one magnet, and, during expiration, a second magnet. These magnets controlled two metal rods which were suspended before the camera slit of the electrocardiograph apparatus, so as to throw a shadow on the moving film. This film, within a specially constructed camera, is used for recording the cardiac changes; the arrangement described was for the purpose of simultaneously registering the respiratory changes upon the same record. This apparatus thus registers the beginning and duration of the two respiratory phases. It does not measure amplitude nor the pauses.

When the handle was pulled back, thereby releasing the chair, a contact was made which activated a third magnet controlling another metal rod the movements of which were likewise registered upon the film. In this way the actual time of falling was recorded and the temporal relations of the physiological changes could be analyzed.

A Jacquet time-marker registered seconds on this film by interposing the recording lever between the source of light and the camera-slit.

The shadow of the galvanometer string was focused at the center of the slit at the beginning of each experiment by means of the compensating device. This position was considered 'zero' in measuring any deflection of the shadow.

By simultaneously recording all of the changes upon the same photographic film a synchronous record of the changes studied was obtained. The film was moved behind the camera-slit by a small motor, permitting continuous records to be taken for as long a period as desired. The record for

[3] This instrument is described in detail by H. K. Nixon in the JOURNAL OF EXPERIMENTAL PSYCHOLOGY, Vol. VI., 1923. We have arranged a recording device to suit our conditions.

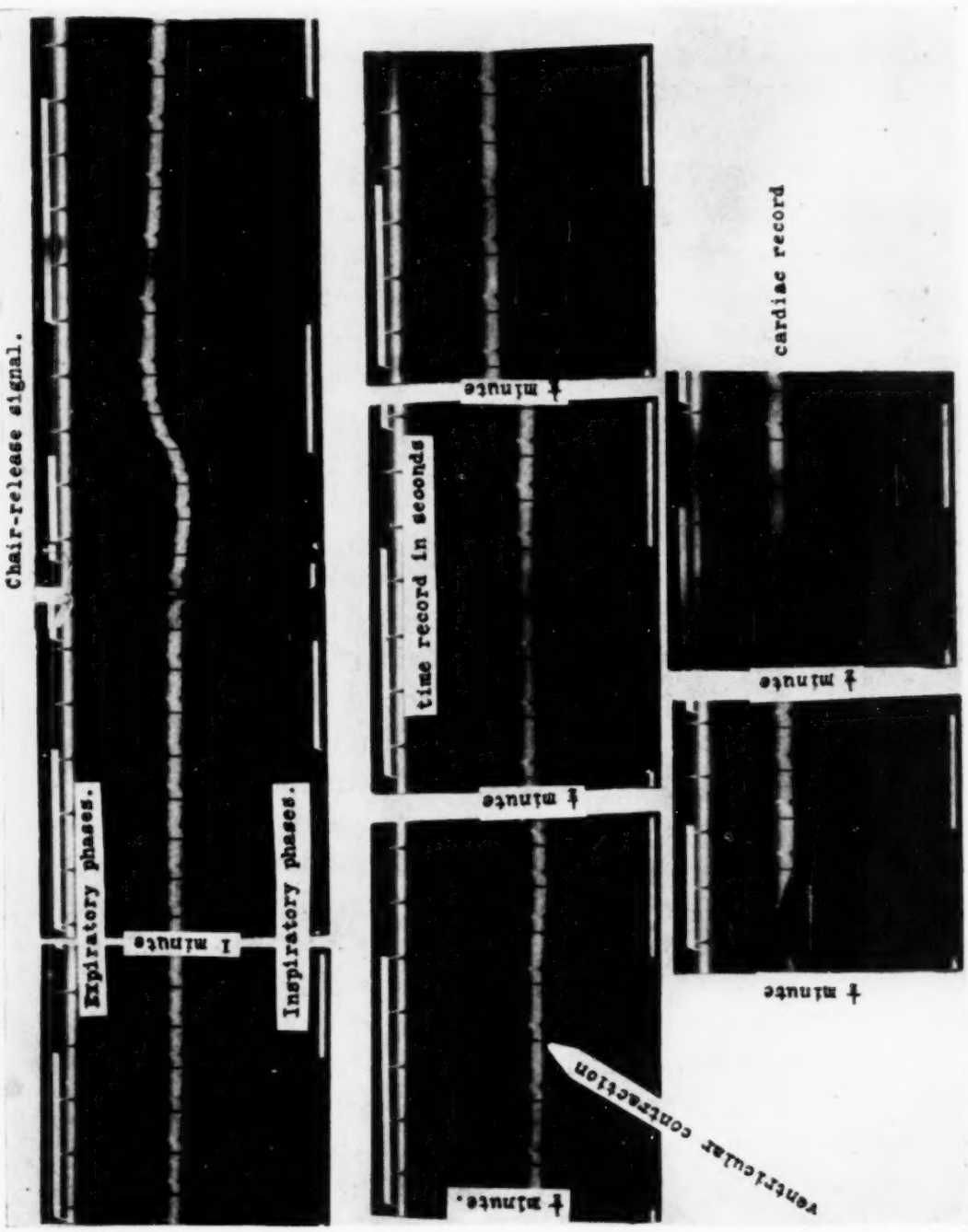

Chair-release signal.
Expiratory phases.
1 minute
Inspiratory phases.
1 minute
time record in seconds
1 minute
cardiac record
1 minute
1 minute
ventricular contraction
1 minute.

FIG. 2

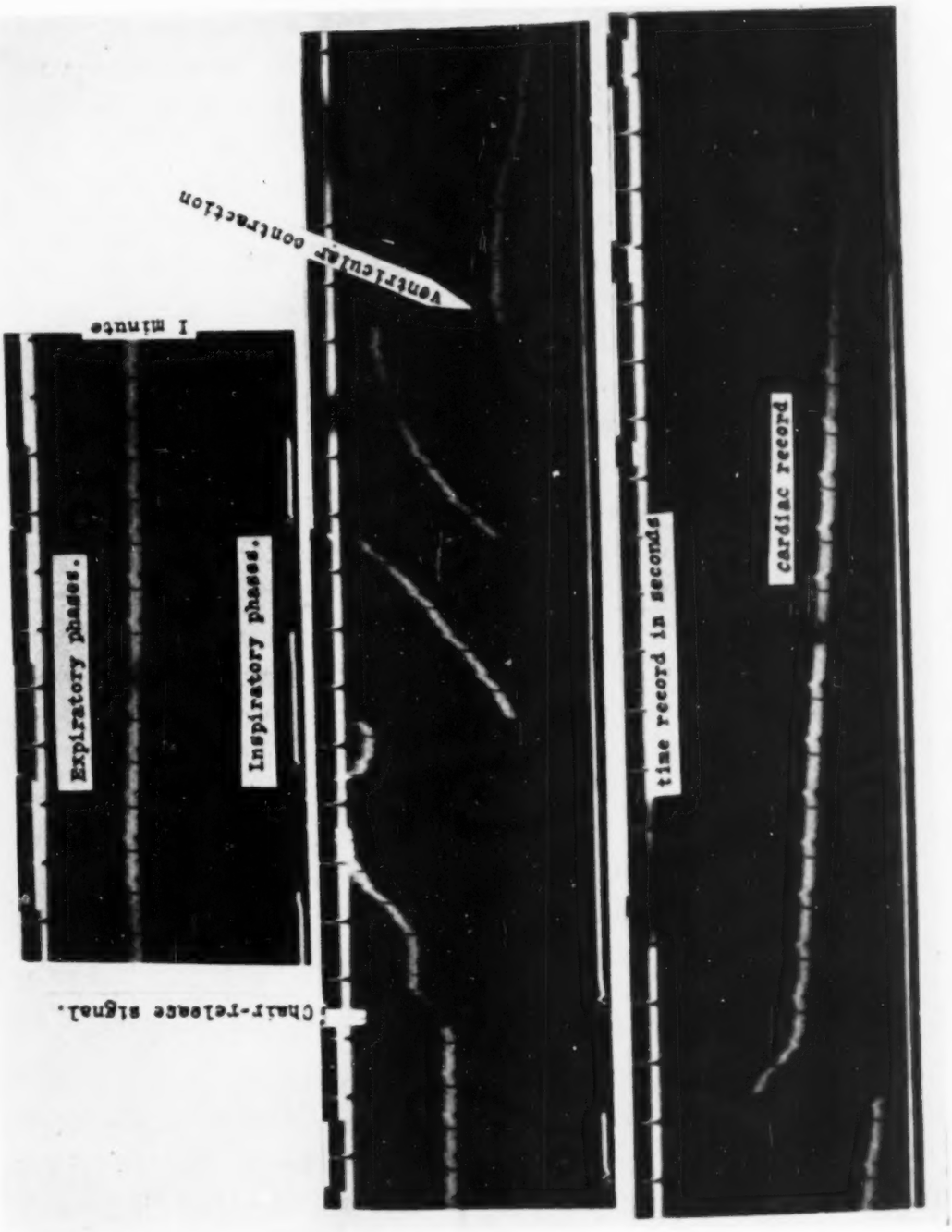

cardiac record
time record in seconds
Inspiratory phases.
Expiratory phases.
1 minute
Ventricular contraction
Chair-release signal.

FIG. 3

each subject for one observation was taken for a period of about 8 minutes. The length of film approximated 14 feet. For purposes of illustration typical excerpts have been taken from various portions of two records and are shown reduced about one-half (see Figs. 1 and 2). The time intervals between the excerpts have been indicated by labels in the figures, *e.g.*, '1 minute,' and '$\frac{1}{2}$ minute.' The records should be read from left to right. The faint parallel straight lines on the record are due to the shadows thrown upon the film by scratches ruled upon the camera-lens. They are 1 mm. apart and are used to measure the amount of deflection.

In the center of the record is the line caused by the shadow of the galvanometer string. Any deflection of this line is occasioned by changes in the electromotive force of the body. The degree of the deflection is a proportional measure of the intensity of the change. Sometimes the deflection after the fall was so great that the shadow was brought back to 'zero' and hence 'breaks' appear in this line. Three such compensations were necessary in the middle excerpt represented in Fig. 2. The lower excerpt (*C*) is a continuation of the former and it is seen that the string has begun to deflect in the opposite direction, towards recovery. Compensation in the opposing direction has been necessary. The registration of these compensations is unmistakable and they are included in the tabulation of results.

At periodic intervals there is a sharp deflection, and recovery, due to the ventricular contraction. These deflections may be used to measure the rate and force of the cardiac activity.

The solid lines appearing at intervals upon the lower part of the record indicate the inspiratory phases. The beginning of an inspiration is measured from the beginning of the corresponding mark (reading from left to right). The expiratory phases are shown at the top of the record, the beginning of an expiration being indicated by the beginning of one of these marks. With our arrangement the expiratory marks are superimposed upon the time-line but may be readily distinguished from it.

The release of the chair is recorded by a solid mark at the top of the record as indicated by the label in the figure.

The first excerpt (*A*), at the upper left-hand corner of Fig. 1, is from that portion of the record taken before the fall. One minute has been omitted and the record resumed. At the 7th second, reading from this interruption, the chair release signal is noted. Changes appear simultaneously in the string line. The cardiac deflections are closer together, indicating an accelerating heart rate. There also appears a gradual deflection, upwards, of about 5 cm., the recovery from which is gradual. Note also the interruption of an expiratory phase by an inspiratory activity. Excerpts after $\frac{1}{2}$ minute intervals have been included to show how it is possible to follow the changes for a continuous period after the stimulus has been presented.

The same symbols have been employed in Fig. 2. This record was selected as an example of the magnitude of the gradual deflection of the string following the emotion of fear in some individuals.

Altogether, 21 subjects were employed throughout the study. From these 280 separate records were obtained. The records occupied a total of 1,600 feet of film. Each record was analyzed carefully and the results for each individual were tabulated. The methods of calculation employed were as follows:

The cardiac changes were examined from the point of view of rate, rhythm and force. To obtain the values for rate, the venticular contractions in successive five-second intervals were counted. The point of reference in all cases was the application of the stimulus. The data thus obtained gives a means for determining changes in the rate throughout any one sitting or changes from sitting to sitting, as well as for ascertaining individual differences.

The regularity of the cardiac rhythm was determined by comparing the duration of the successive heart cycles measured in twentieths of a second. Any deviation from the average is a measure of the degree of the regularity.

Since the string was kept more taut than is usual for

taking electrocardiograms, its sensitivity was thereby reduced. Hence the force of the ventricular contraction is not clearly indicated by the amount of deflection of the string. Changes of the force were readily observed but quantitative measurement was not practicable.

For tabulating the changes in the respiratory activity, the records were divided into groups of ten consecutive respiratory cycles and these units were analyzed with reference to rate, regularity and respiratory index. The average duration of one complete cycle from the beginning of inspiration to the end of expiration was used as a value to indicate rate. This value was expressed in seconds and tabulated. For example, a value 4 indicates that for the group in question, the average duration of one complete cycle was 4 seconds, the duration of the ten cycles was 40 seconds or in other words, 15 per minute. The regularity was measured by the difference in the rate of consecutive groups.

The respiratory index is a value obtained by dividing the time for inspiration by the sum of the time for expiration and the time for the pause which normally occurs after expiration. From our records the time between the beginning of inspiration and the beginning of expiration was taken as the time for inspiration (I) and from the beginning of expiration to the beginning of the next inspiration as the time for expiration (E). The index is obtained by finding the value for the fraction I/E. This value was obtained for each group of successive respirations.

Any change of the electromotive force of the body other than cardiac is indicated by a gradual deflection of the string. This deflection may be measured in millimeters. Since the string is adjusted at the beginning of the experiment, the amount of deflection from this position may be ascertained. This value has been obtained for each five-second interval and recorded graphically. At the beginning of each observation the string-sensitivity was adjusted to a constant standard. Since the resistances of the subjects was not measured, comparisons of individuals from a quantitative point of view are not justified with our data. The values obtained from

the same individual during different sittings, however, may be thus compared. Qualitative changes are comparable throughout the whole experiment and among all of the subjects.

Experiment I

The purpose of the first experiment was to observe the cardiac, respiratory, and electrical changes, following a fall, in wholly naïve subjects who knew nothing of the problem to be investigated.

Eighteen beginning students [1] in psychology (7 male and 11 female) volunteered as subjects. They were kept in total ignorance as to the nature of the experiment. They were blindfolded in the entrance room to prevent them from seeing the apparatus, which would have suggested its purpose immediately. They were tied into the chair to prevent bodily movements during and after the fall. Nothing unusual was suggested, and to allay suspicion and satisfy curiosity they were all given the same verbal instructions on the first day, as follows:

> This is an experiment to discover the differences that occur in the heart rates of individuals. In order to compare the records we must have as perfect relaxation as possible. To help you to relax we will blindfold you to avoid visual distraction. You will be taken into an adjoining room and seated in a Morris chair. Your arms and legs will be fastened to the chair so that all random movements will be eliminated. Two electrodes will be applied which are for the purpose of leading electric currents away from the body and under no circumstances will you be given a 'shock.' You will remain in the chair for about 15 minutes, so try to relax. Go to sleep if you wish.

All subjects were first given a series of three normal sittings to approximate the normal physiological state. The procedure during one sitting was as follows: After blindfolding the subject and fastening him into the chair and applying the electrodes, the experimenter left the room and went to the recording room. When all adjustments had been made, a record was taken for about 2 minutes and an interval of 2 minutes elapsed before a second record of the same duration was taken. These records are called 'normals.' The subject remained in the chair for about 15 minutes in all,

[1] Since the pneumograph was not completed until some time after the beginning of the study, only four members of this group show respiratory records.

after which he was released and led back to the entrance room where the bandage was removed from the eyes and any observations or remarks were recorded. An appointment was made for the next sitting and the subject was dismissed. The sittings were not necessarily held upon successive days. It was found that at the end of the third period the signs of excitement and 'nervousness' had disappeared. It was evident from their behavior that the subjects were more at ease. They would converse on current topics during the preliminary bandaging and adjustment. Typical comments were, 'was almost asleep today,' 'my mind was far away,' 'this certainly is restful,' etc.

The first fall was always given during the fourth sitting. On this day the same routine procedure was followed. A preliminary record was taken which is called the 'fore-period.' These records are comparable to the 'normals' described above. After this fore-period the record was again begun and after $\frac{1}{2}$ minute the handle which released the chair was pulled. The record was continued uninterrupted for about 2 minutes and then $\frac{1}{2}$ minute intervals alternated with $\frac{1}{2}$ minute records for 6 minutes. The observations of the subjects after the fall, of course, varied, but they were sufficiently in agreement to indicate the arousal of genuine fear in naïve subjects. Some examples of these remarks were, 'startled,' 'surprised,' 'frightened,' 'scared,' etc. In most cases the subjects cried out, and some called the experimenter by name. They all made some effort to escape, thinking an accident had happened. In all cases they acknowledged that they had not anticipated 'anything like it at all.' From these statements, it was concluded that the stimulus was wholly unexpected, and unsuspected.

During the fifth sitting the fall was repeated. The same routine as in the previous sitting was observed but before leaving the room the experimenter told the subject that he was to expect a fall but that there would be no warning to announce the stimulus. The conditions thus differed from the first sitting in that the subject knew what to expect. A record was taken in the fore-period as usual.

From this stage on, the subjects were divided into two groups, for which the procedure differed. The subjects of the first group (*A*) were run through a second set of 2 'normals' in order to approximate the conditions obtaining before the first fall and then they were dropped unexpectedly during the final sitting during which they expected only a normal routine. The subjects of the second group (*B*) [1] were subjected to a series of eight falls during two succeeding sittings of four falls each. They were placed in the chair as formerly and then were told that they would be dropped four times in succession. There was no specific warning before each fall, but, since the chair had to be raised before it could be dropped again, the same period of anticipation ensued before each fall. About 4 minutes elapsed between each fall and the record was taken continuously during this time. This same procedure was repeated during the next sitting. This group was then given the set of 'normals' and on the final day were dropped unexpectedly as in group (*A*).

After all the subjects had completed this series they were brought back to the laboratory and placed in the chair while it was in the *horizontal* position. A record was taken after a few minutes. The chair was then raised to the vertical position and the record was continued for some time thereafter. This was done for the purpose of observing the effect of the difference in bodily position on the cardiac and electrical conditions.

The results will be discussed with the following general problems in mind: (1) What changes take place during adaptation to the novel conditions of the experiment during the three preliminary 'normal' periods? (2) What is the effect of an unexpected fall? (3) Is there any adaptation to this fall if it is repeated with the knowledge of the subject? (4) What is the effect upon the adaptive process of successive falls? (5) What is the effect of a fall upon the subsequent fore-period? (6) What effect has the experience of falling upon a second adaptation to normal conditions? (7) What is the difference in the reaction to a second unexpected fall?

[1] There were no respiratory records taken for this group.

(8) What is the immediate effect of the fall upon the respiratory rhythm? (9) Did the fall induce a genuine experience of fear? (10) What changes accompany a difference in bodily position?

TABLE I

CARDIAC AND RESPIRATORY RECORDS OF EXPERIMENT I

	Pulse Rate			Resp. Index. 4 Subj.	Respiratory Rate	
	Average 18 Subj.	Group *A*	Group *B*		Seconds per Cycle	Number per Min.
1st normal	92.0	87.0	100.0	.67	4.2	14.3
2d normal	89.0	85.6	94.0	.85	4.7	12.8
3d normal	83.3	82.6	84.6	.72	4.4	13.6
Fore-period 1st fall	88.0	85.4	91.8	.74	4.3	13.9
Fore-period 2d fall	91.3	88.3	95.4	.70	4.5	13.3
Fore-period 1st Succ.			95.8			
Fore-period 2d Succ.			92.7			
1st second normal	87.4	84.2	92.4	.57	4.8	12.7
2d second normal	83.4	82.7	84.3	.59	4.2	14.3
Fore-period unex. fall	82.5	82.4	82.8	.67	4.1	14.6

1. A tendency towards a slower heart rate seemed to be the most striking feature of the adaptive process throughout the three normal periods (Table I). The averages for the three periods for the whole group were 92.0, 89.0, and 83.3 respectively. The rate for group *B* was consistently higher due to the chance inclusion within this group of the two subjects having the highest rate throughout the experiment. A similar tendency towards diminution in the force of the heart rate was not demonstrable. During these three periods the rate of breathing remained fairly constant, from 12 to 14 per minute. The respiratory index was also constant and remained between .65 and .85. The value of the respiratory index in no case exceeded unity. This condition is described as the physiological normal. The electrical phenomena were similar in all three sittings.

2. The changes following the first fall were quite marked. (i) The pulse rate (solid line graph 1) was immediately accelerated from 88 per minute to 102 per minute. This period of acceleration lasted for about 5 seconds and was followed by a period of retardation lasting about 10 seconds.

A second phase of acceleration ensued, not quite so marked in degree but of a longer duration. This was followed by a gradual retardation until about the third minute when there was a tendency towards acceleration to a slightly higher level which remained constant. This final rate was always lower

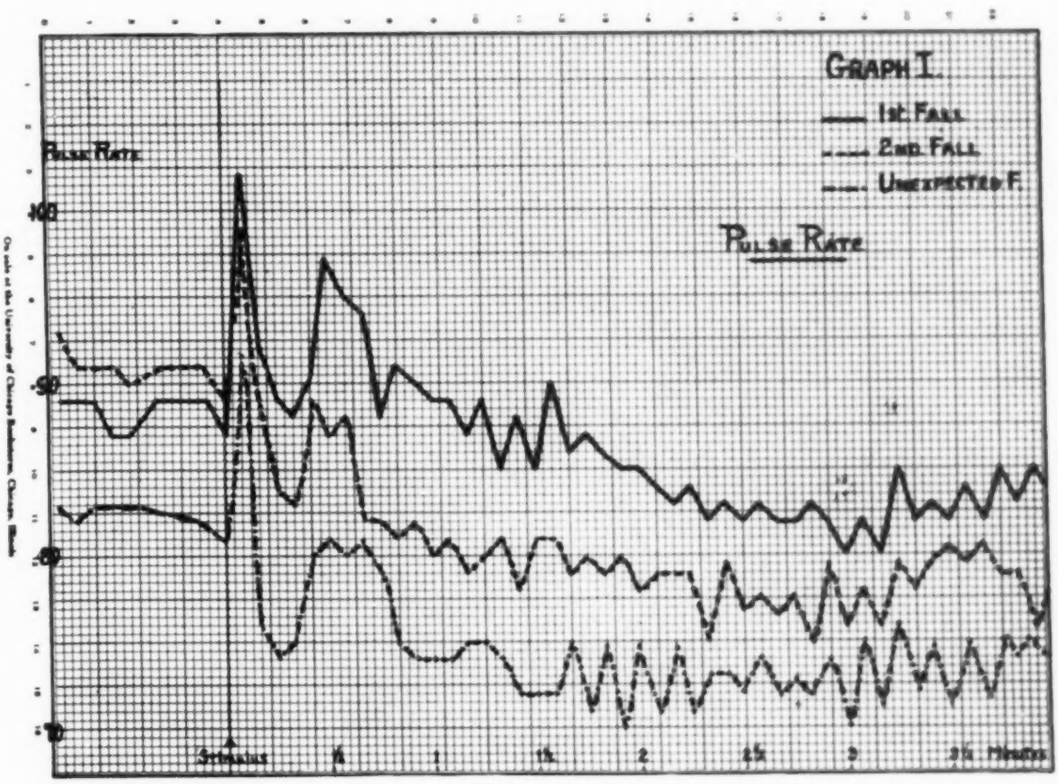


FIG. 4

than in the fore-period because of the change of the position of the body from the perpendicular to the horizontal plane. (ii) Following the fall there was an immediate increase in the force of the ventricular contraction which reached a maximum within the first few beats and then, with only a slight decrement below this level, this augmented force persisted throughout the whole record. The force, therefore, remained slightly augmented even after 6 to 8 minutes. An example is included. The figures represent the deflection in millimeters of the shadow due to ventricular contraction—8, 8, 8, 8, 8, 8, 8, 8, 8, 8, 8 (fall), 9, 9, 10, 9, 9, 10, 9, 9, 9, 9, 10, 10 (1 min.), 9, 9, 9, 10 (5 min.), 9, 9. (iii) The regularity of the rhythm was disturbed after the fall. The maximum deviation from the

average, in the fore-period, was 0.05 sec.; immediately after the fall the deviation, within the first ten heart cycles, was from 0.2 sec. to 0.4 sec. This irregularity was in evidence for about 2 minutes after which it was not distinguishable from the normal. (iv) The respiratory changes after the fall

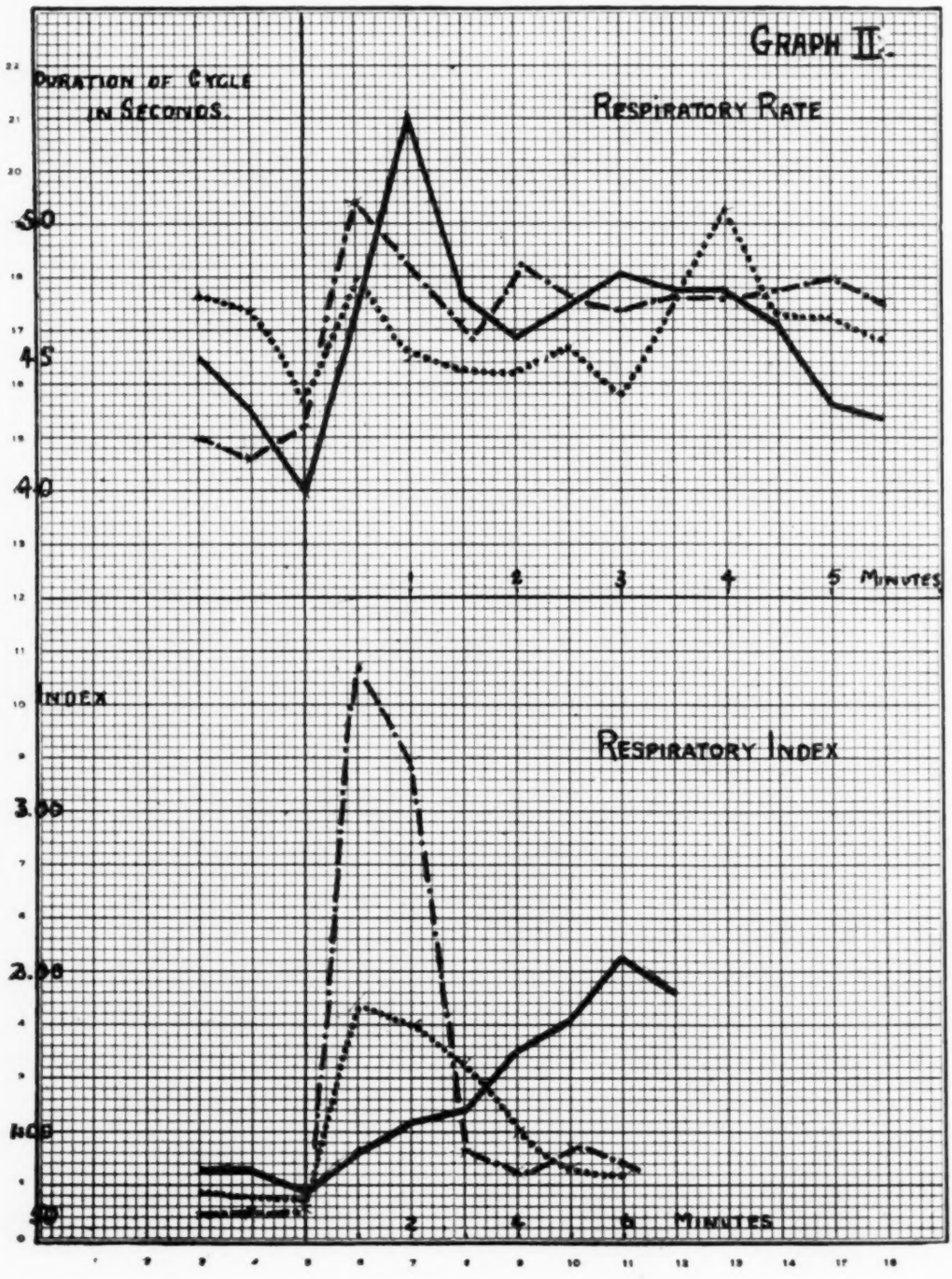


FIG 5

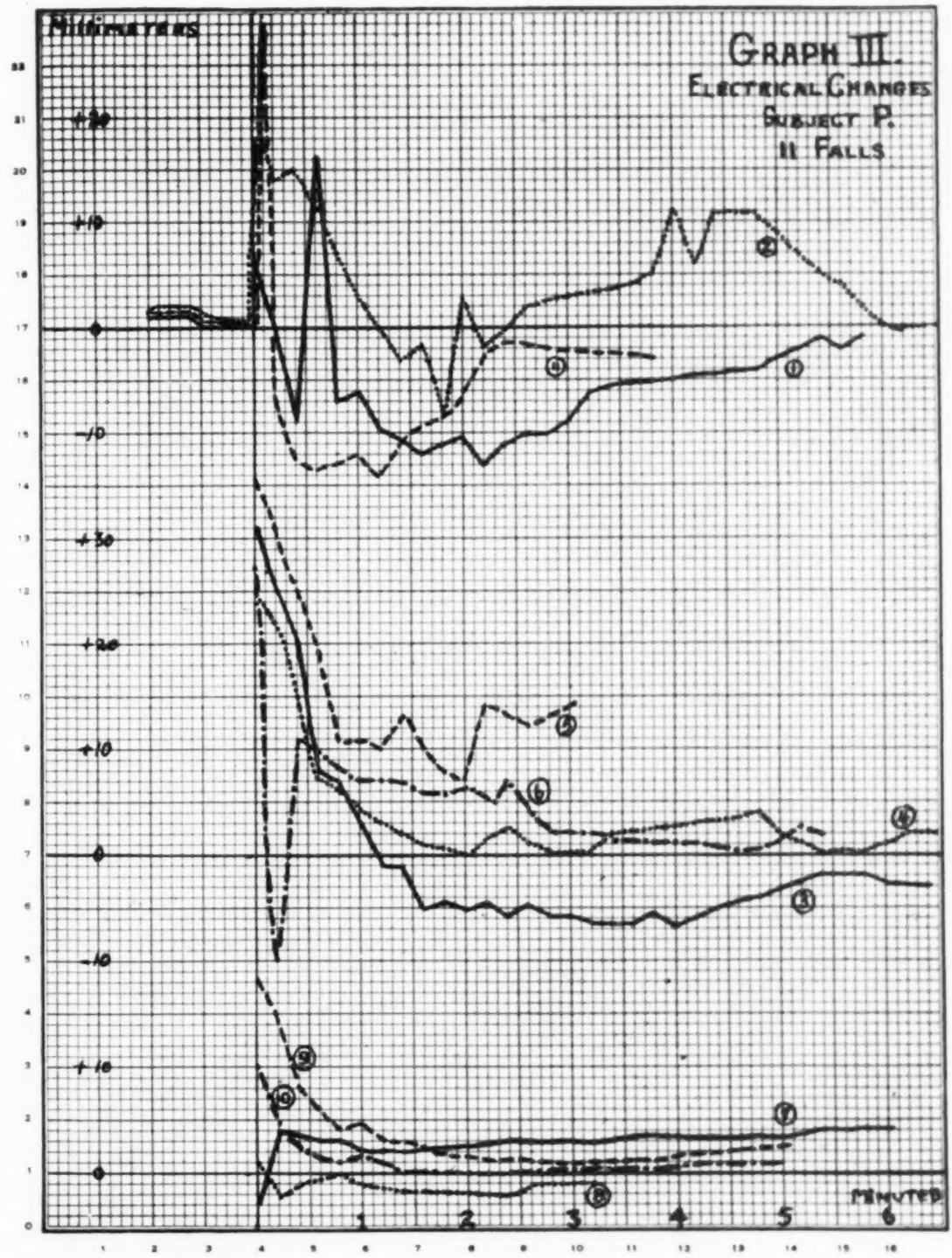

GRAPH III.
ELECTRICAL CHANGES
SUBJECT P.
11 FALLS
MILLIMETERS
+30
+20
+10
0
-10
+30
+20
+10
0
-10
+10
0
MINUTES
1
2
3
4
5
6

FIG. 6

consisted of (*a*) an immediate retardation of the rate from 13.9 in the fore-period to 11.1 per minute (graph II.).[1] There was an early recovery of the rate from this level but the

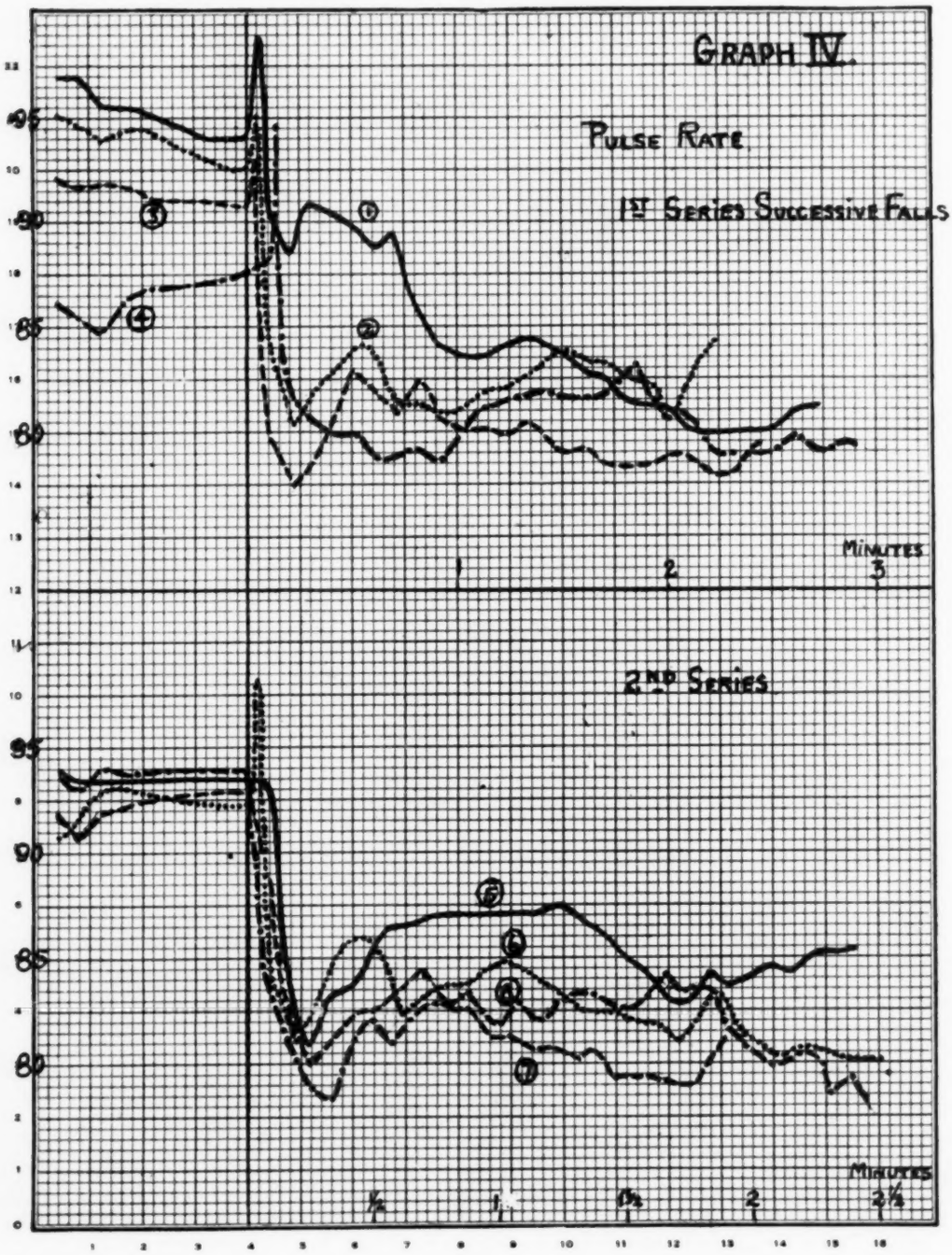


FIG. 7

[1] The graphs were made from the original data which give duration of the respiratory cycles in seconds. Hence an upward trend in the graph indicates a retarded rate.

retardation was apparent until the later stages of the record. (*b*) The respiratory index (graph III.) increased in value after the fall. This value became larger than unity very soon after the fall and was maintained at this level throughout the period. (v) The electrical changes were very striking. In the fore-period and normals the string remained fairly consistently at 'zero.' At the time of the falling there were a few wide excursions, due no doubt to the change of bodily position, lasting for about 0.1 sec. (the duration of the fall). These oscillations subsided and after a latent period varying from 0.5 sec. to 3.0 sec. there was a well marked deflection varying in magnitude from 1 to 10 cm. (*cf.* Figs. 1 and 2). This phenomena appeared in all subjects with wide individual variations. The maximum deflection was reached in about 5 to 15 seconds and then there was a gradual, sometimes fluctuating, return to 'zero.' In some cases a reversal of the direction of the deflection beyond 'zero' occurred.[1] The shadow returned later to the base line. This whole phenomenon lasted for from 4 to 6 minutes. Since changes in the resistance of the circuit do not register in this manner, this change must be interpreted as an indication of the development of electromotive force. Graph III. represents the deflection after falling, for the complete series of eleven falls of one subject from group *B*.

3. The changes initiated by the second fall were qualitatively similar to those following the first fall. There were, however, some quantitative differences, indicative perhaps of some adaptation to this stimulus. (i) The initial cardiac acceleration was not so great (dotted line, graph I.). The ensuing retardation and the secondary acceleration were less marked. Throughout the whole record the rate was below that of the first fall. (ii) The irregularity was about the same as after the initial fall. (iii) There was again a decided augmentation of the force of the heart beat which persisted during the whole record. (iv) The change in the respiratory

[1] A deflection of the string can be occasioned only by a change in the electromotive force of the circuit. The compensating current is constant hence this change occurs in the subject. A reversal of the direction indicates a change in polarity of the electrodes.

rate was not so marked. (v) The change in the respiratory index was more immediate and apparent. There was a recovery to the normal value below unity in about 5 minutes. (vi) The electrical changes were quite marked and in some cases greater than after the first fall (graph III.).

4. An analysis of the effects of the repeated falls showed, (i) the usual qualitative changes in the heart rate but a quantitative diminution of the effect (graph IV.). The initial acceleration was reduced and after the sixth, seventh, and eighth falls this phase does not appear in the graph (examination of the records showed that there was always a slight acceleration but our method of combining the values into 5 second groups obscured this slight acceleration by the ensuing retardation). The retardation was always in evidence. The secondary acceleration always appeared but not to the same degree. There was a gradual diminution of this phase also. (ii) The changes in the electrical conditions did not show this regular diminution in degree, but the amount of deflection varied; it was sometimes greater and sometimes less than after the previous fall (graph III.). There appeared, however, a well marked tendency toward an earlier return to 'zero' during the later falls.

5. The experience of falling exerted certain influences upon the subsequent fore-periods. (i) The pulse rate during the fore-period of the first fall was faster than during the previous normal (Table I.). This was surprising because of the similar routine in both cases. Perhaps the experimenter unwittingly took more care in fastening the subjects and in applying the electrodes. The electromotive force seemed steady throughout this period. (ii) The pulse rate during the fore-period of the second fall was much accelerated, in all cases to a value lying between the first and second normals. The force of the heart beat was in most cases appreciably greater than during the fore-period of the preceding fall. (iii) During the fore-period of the first fall of the successive series of group *B* the heart rate was again fast, 95.8 per minute. (iv) During the fore-period of the first fall of the second successive series the rate was 92.7 per minute. The

fore-periods for the succeeding three sittings cannot be considered in any comparison because they were modified by the immediately preceding fall, the effects of which had not been entirely eliminated. (v) The heart rate during the fore-period of the final fall (the subjects did not know it was to be the final period) of group *A* was the second lowest recorded for this group, 82.0 per minute. In the final fall of group *B*, which was in this case the eleventh, the fore-period showed the lowest heart rate of the series, 82.8 per minute. There is no evidence that the fall exerted an effect upon the respiratory conditions in the subsequent fore-periods. The rate did not fluctuate below 12.7 per minute or above 14.6 per minute during all of the fore-periods and normals. The respiratory index was never above .85 during the fore-periods or normals. These values seemed to be very consistent.

6. The subjects were again asked to relax and were assured that no fall would occur. This second series of normals showed a similar reduction of the heart rate as before. The subjects of group *B* started this series with a relatively higher rate and showed the greatest change; the change was from 84.2 to 82.4 in group *A* and from 92.4 to 82.8 in group *B*. During this second set of normals (Table I.) the respiratory index and rate reached the lowest values recorded. This seems to indicate that during these periods there was more adaptation than during the first set of normals.

7. After the subjects had recovered from the effects of the previous falls and were again at ease, the final fall was given which again was not anticipated by the subjects. The changes resulting approximated most closely those following the initial fall. (i) The effects of this unexpected fall (third) of group *A* were qualitatively similar to those following the other two falls (graph I.). The heart rate throughout all phases was lower than in the others. The percentage increase of the initial acceleration was intermediate between the first and second falls; the values were respectively, for the first, second, and third falls, 16 per cent., 9 per cent., and 12 per cent. The change in the force was just as marked and prolonged as after the first fall. (ii) The respiratory rate

was markedly retarded and remained slower than normal throughout the period. (iii) The respiratory index showed an exaggerated increase in value (this effect was due in large part to two of the subjects) but the recovery was earlier than in the first period. (iv) The electrical changes were again conspicuous with wide individual variations. (v) The effects of the unexpected fall (eleventh) of group *B* were similar to those of group *A*, with the following differences due to the previously repeated falls experienced only by this group: The heart rate was about equal in the fore-periods but the initial acceleration of the 'unadapted' group, *A*, was greater, as was the case with the retardation. From this point the two records were similar. The faster rate of group *B* in the later stages is due to the fact that the average rate of this group throughout the whole experiment was slightly faster than for group *A*. (vi) Comparing the effects of this fall with the preceding successive falls showed that it resembled more closely the first falls. (vii) The electrical changes were more like those of an initial fall and showed little influence of adaptation (graph III., line marked eleven).

TABLE II

INITIAL EFFECT OF STIMULUS UPON RESPIRATORY PHASE

(E.I.—expiration interrupted. I.C.—inspiration continued.)

Subject	1st Fall	2d Fall	3d Fall
A	E.I.	E.I.	I.C.
B	E.I.	E.I.	E.I.
C	E.I.	I.C.	E.I.
D	I.C.	E.I.	E.I.

8. The respiratory phase, during which the stimulus happened to be given, was sometimes inspiratory and sometimes expiratory. From Table II. it will be observed that whenever the stimulus occurred during an inspiratory phase, this phase was continued as such. Whenever the stimulus occurred during an expiratory phase, this phase was interrupted and an inspiratory phase initiated. These results were consistent.

9. All of the subjects were unanimous in calling the

emotional experience following the first fall some form of fear; it was noticed that there was also, in all cases, some attempt to escape from the chair. Upon the repetition of the stimulus in a subsequent sitting none of the subjects labelled the experience 'fear' and upon further questioning specifically denied such an emotion. In none of the subjects was there any evidence of a response in the form of escape. This tendency had been eliminated. The organic response was the same in both cases except for a diminution of the effect in the second occurrence. From this it may be concluded that there are two components necessary for the experience of a genuine emotion of fear, (i) an organic response of great complexity, and (ii) a gross skeletal response of an adaptive nature. Of the two, the second appears to be the more important. At least, in its absence the subject does not label the experience 'fear.' The temporal priority of one or other of these responses seems a fruitless problem

10. In the final test-period during which the subjects were placed in the chair in the horizontal position and then elevated to the vertical, the average heart rate was 5.5 per minute (varying from 2 to 12 per minute) faster during the vertical. There was a slight irregularity in the rhythm during the elevation of the subject. There were no electrical differences.

Experiment 2

The previous experiment was conducted with naïve subjects. This experiment was arranged to investigate the effect of the same stimulus upon subjects who were informed about the nature and purpose of the experiment. Three graduate students in psychology were employed. They were not blindfolded but were taken directly to the chair-room where the apparatus was described to them. They were then fastened into the chair and the electrodes were applied. They were not given a set of normals but were dropped on the first day. There was no immediate warning before the fall, but the subjects were expecting the stimulus. Upon the second day this routine was repeated. On the third day the subjects were brought back and placed in the chair in

the *horizontal* position and then raised to the vertical (as in experiment 1).

Table III

Comparison of the Effect of the Initial Fall with Naïve, and with Informed Subjects

	Naïve	Informed
Cardiac responses:		
Initial acceleration	16%	11%
Ensuing retardation	to normal	14%
Secondary acceleration	10%	7%
Duration of the effect	3 mins.	2½ mins.
Respiratory responses:		
Change in rate	14–11 (20%)	16–14 (12%)
Duration	5 mins.	3 mins.
Change in index value	.74–2.08	.80–1.61
Duration	5 mins.	3 mins.
Inspiratory stimulation	marked	marked
Electrical responses:		
Degree	marked	fairly marked
Duration	6 mins.	2 mins.

Table 3 gives a comparison of the effect of the same stimulus upon subjects with different preparation for the stimulus. Knowledge of the expected event reduces the intensity of the effect produced. The effect is also less prolonged.

Table IV

Comparison of the Effects of the Second Falls with Naïve, and Informed Subjects

	Naïve	Informed
Cardiac responses:		
Initial acceleration	10%	15%
Ensuing retardation	9%	20%
Secondary acceleration	to normal	4%
Duration of the effect	3½ mins.	2 mins.
Respiratory responses:		
Change in rate	slight dec.	slight inc.
Duration	1 min.	—
Change in index value	.70–1.85	.95–1.40
Duration	5 mins.	2 mins.
Inspiratory stimulation	marked	marked
Electrical responses:		
Degree	marked	fairly marked
Duration	5 mins.	2 mins.

The extent of the adaptation to the stimulus is shown in Table IV. The difference between the effects of the first and second falls in the case of the 'naïve' subjects is greater than the difference in the 'informed' group.

The records show that the effect of the experience of falling upon the 'informed' group did not increase the heart rate for the subsequent fore-periods which in this case was lowered from 85 per minute in the first fore-period to 69.5 per minute in the second.

The reports of these three subjects did not show any indication of experiencing fear. They reported that the fall was 'not as bad as expected,' 'released the tenseness of waiting for it,' 'glad it was over.' They made no attempt at escape.

The change produced by raising the subjects from the horizontal to the vertical position were as follows: (i) an increase in the heart rate from 68 to 77 per minute, (ii) a decrease in the respiratory rate from 17 to 13 per minute, and (iii) a change in respiratory index from .79 to .72.

Summary

1. The only adaptive process that was manifested during the three normal sittings was a reduction in the heart rate in 12 of the 18 subjects. This change was not observed in relation to the cardiac rhythm nor in the electrical conditions. In 4 of 7 subjects there were only slight indications of adaptation as far as respiratory changes were concerned.

2. The sudden arousal of the emotion of fear, by falling, involves the following changes: (i) Cardiac—(*a*) an immediate initial acceleration followed by a decided retardation, then a less marked but more prolonged acceleration phase, and finally, a subsequent gradual retardation, (*b*) an initial augmentation of the force of the heart beat which persists with but slight decrement for longer than 6 minutes, and (*c*) a marked irregularity of the cardiac rhythm. These changes were observed in all of the subjects. The degree of the change differed with individuals as did the duration of the effect. (ii) Respiratory—(*a*) an immediately retarded

rate in 9 out of 11 records, (*b*) an increase in the value of the respiratory index above unity in 9 out of 11 records, and (*c*) an inspiratory stimulus during falling in all cases. (iii) Electrical—striking changes in the electrical conditions of the body in the nature of an increased development of the electromotive force. This effect had a latent period of 0.5 sec. to 3.0 sec., and was prolonged over a period of 1 to 6 minutes. There were no exceptions to the appearance of this phenomenon after falling.

3. There are two essential components of a response to a stimulus in order that the subject label the experience 'fear,' (i) an organic response of complex nature, and (ii) a gross muscular adaptive response.

4. Information regarding the stimulus reduces the organic effect which it produces.

5. Repetition of the falling, with knowledge of the subject, decreases all of the effects in degree and duration with the exception of the respiratory index which reaches a high level after the second fall in 6 out of 7 cases. The duration of the effects were reduced in all subjects.

6. Repeated presentation of the stimulus, with knowledge of the subject, exaggerates the adaptive effect.

7. Anticipation of the stimulus, after having once experienced it, caused an increase in the heart rate in 15 out of 18 subjects.

8. Assumption of a normal condition, after a period of stimulation, is always accompanied by a decrease in the heart rate.

9. An unexpected presentation of the same stimulus within a relatively short time will overcome the adaptive effect and produce effects which resemble those of the initial fall.[1]

[1] Acknowledgment is made herewith to all of the subjects who, by submitting so faithfully and willingly to the exigencies of the technique, have made this research possible; to Dr. A. J. Dempster of the Department of Physics, and to Dr. A. J. Carlson of the Department of Physiology, who very graciously assisted with valuable advice; and to the staff of the Department of Psychology. I wish especially to thank Dr. H. A. Carr for his painstaking efforts in planning and developing this study, and for the privilege of working under his guidance.

A NEW METHOD OF PROJECTION STEREOSCOPY[1]

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It is nearly three quarters of a century since Sir David Brewster reported to the Royal Society (1) his prismatic method of viewing small stereoscopic pictures in relief. Although his various forms of prismatic stereoscope as well as the earlier mirror type of Professor Wheatstone (2) both place very distinct limitations upon the conditions of experimental stereoscopy, these two methods have remained practically unaltered as the basis of stereoscopes that are used today.

This survival of the principle indicates the strength and also the weakness of the stereoscope as an instrument of visual science. To the extent that the stereoscope permits objective control of the presented subject matter (*e.g.*, when plane pictures are the material to be fused) its importance for investigating binocular vision has always been recognized. Its limitation from a scientific standpoint has been the narrow range of presentation conditions and of material with which it could deal. Originally the stereoscope could utilize the best that photography had to offer but this has long since ceased to be the case. Great changes have occurred in the photographic and cinematographic arts both as regards the quality of pictorial matter and the manner of presenting it, particularly public presentation in large size by optical projection on a screen. With these advances the principle of the stereoscope has not kept pace. Today should one desire to use or to demonstrate a stereoscope one naturally but somewhat apologetically resorts to the early form of instrument and those small binocular slides such as our forebears viewed at the Exhibition of 1851. A half century of trivial

[1] Presented before the Psychology Section of the British Association for the Advancement of Science, Toronto, August 8, 1924.

publicity on the one hand and failure to adapt to improved facilities on the other have contrived to dethrone the stereoscope from the place its eminent inventors gave it in research upon vision. In fields of practice it survives only where stereoscopic matter of small or portable dimension may require to be fused in relief.

The recent growth in the use of projected pictures especially of motion pictures has made projection stereoscopy an obvious, though as the event has proved, a difficult problem. In this connection it is curious to note in the first place that the stereoscope should have been ignored as irrelevant, the solution of the problem being sought in other directions, and secondly, that the motive for securing depth with projected matter should have remained, as it has, almost entirely a commercial one.

The present lack of scientific interest in this difficult phase of stereoscopy particularly among experimental psychologists is to be lamented, not merely because of the bearing its solution will inevitably have upon an important industry but mainly because the solution will open a range of experimentation now unknown in visual science. It will permit control, for example, of the objective conditions in relatively long distance binocular vision (at 100 feet or more) as readily as in the extremely short ranges of a few feet or inches at which existing stereoscopes usually require the picture material to be presented. Projection stereoscopy is certainly not too trifling a problem for pure science and as yet only tentative solutions are in sight. Although the stereoscope will probably not be the final solution of the problem, in principle it offers greater possibilities than have been realized. In this article we shall report upon certain simple and inexpensive forms of prismatic stereoscope which are effective for fusing stereoscopic material under a wide range of presentation conditions including those of projection.[1]

Reference may first be made briefly to certain points of principle. Stereoscopic observation of nature involves a

[1] On another occasion some of the specific problems and findings in stereoscopic vision which these improved means of objective control are bringing to light will be dealt with.

number of variable factors, physical, physiological and psychological so correlated that perception of visual depth as known in daily life results. In experimental stereoscopy, *e.g.*, when plane photographic material of suitable kind is observed in lieu of its counterpart in nature, appropriate control of certain of these variable factors likewise results in stereoscopic perception. In this case we would postulate that this psychological resultant, the immediate quality of depth perceived, is the ultimate criterion by which the experimental undertaking must be judged, and further, that experimental stereoscopy is successful *only* to the extent that the observer actually perceives from the presented material as perfect a stereoscopic effect as he would if viewing the natural world and with no greater effort or other undesirable result.

These apparently obvious criteria are emphasized because of the temptation there often is in connection with stereoscopy to dwell upon certain of the conditioning factors and to ignore or assume the actual character of the visual outcome. Because under experiment the relationship of variables which gives the optimum visual result differs significantly for different observers and under certain circumstances may differ considerably for the same observer, and because the degree of perceived depth is itself a gradable factor that can be made to vary from zero (or flatness) to an optimum for any observer who has ordinary binocular ability, it follows that no unequivocal definition of the objective conditions of stereoscopic vision can be given. Nevertheless an approximate definition that will allow for individual differences is useful and on this ground the conditions essential for experimental stereoscopy may conveniently be defined as two. Whether these two conditions are fundamental in the sense of carrying all others in their train and whether they are themselves absolutely indispensable for obtaining the optimum depth effect remains for the future to decide.

The first of these conditions is that there must be two views which are dissimilar through being registered (*e.g.*, photographically) from two discrete points of outlook upon the original three dimensional data, and that by suitable

means these dissimilar views must be presented singly to the eyes, one to each, not both to both. In general terms therefore this condition is *single dissimilar presentation.*[1]

The second condition pertains to the degree of convergence of the eyes when they fixate the singly presented views so that unitary vision with full relief results. Although the fact of convergence is usually patent in binocular vision, it is not easy to determine or to define the amount of ocular convergence that is required experimentally in order to obtain the desired stereoscopic effect. In daily life appropriate binocular convergence, normally learned in infancy, is continually accomplished with a minimum of effort by all but perhaps a small minority of individuals who have the use of both their eyes. Under experimentation when discrete monocular fields are used this habitual control of convergence by the ocular motor apparatus greatly complicates the inquiry. In the first place convergence is intimately associated with ocular accommodation that gives sharp definition; but the exact degree to which accommodation is conditioned by convergence or vice versa, or, on the other hand, the degree to which these factors are independent variables or may be made so by training, is, under given circumstances, usually unknown. Accurate information upon convergence would require objective registration of the movements of both eyes, vertically as well as horizontally, during a subject's visual exploration of selected stereoscopic material, but such measurement while perhaps not impossible is obviously

[1] Detailed requirements under this condition are sometimes assumed to be essential but these are in the nature of special cases and are not fundamental. It is sometimes assumed, for example, that for optimum depth a particular view must be given to a particular eye, the left aspect to the left eye and the right to the right. But as will be shown in a later communication this provision is not necessary, for optimum depth can be readily obtained whichever view is shown to whichever eye, the essential point with respect of the two eyes being simply that of single presentation. Again as regards dissimilarity, if the hypothetical line joining the registration positions of two views be termed their *base of registration*, it is sometimes assumed that this should be of a particular length, approximating the interocular distance. But this depends very largely upon the objective subject matter. In different circumstances this base may differ enormously in length with satisfactory visual results, nevertheless in general the views must be dissimilar.

difficult to make.[2] For this reason instead of relying upon direct objective measurement resort is usually had to the assumption that the degree of ocular convergence under given circumstances is such as the hypothetical lines of regard would reveal if drawn from the optical axis of each eye to the point fixated in each field. Unfortunately this conception of convergence is theoretical rather than strictly quantitative, there being no very reliable criterion subjective or objective of what point or area the eyes at any time do monocularly fixate when regarding dissimilar views. And especially is this the case when the monocular fields are rendered independently mobile by instrumental means.

Although convergence is difficult to delineate in terms of visual or of objective fact, it can be brought under experimental control and varying it conspicuously affects the stereoscopic result. Approaching the question from this angle the optimum stereoscopic effect can be used as a psychological criterion to define effective convergence for experimental purposes. From this standpoint successful stereoscopy with juxtaposed pictures will involve that whatever be the dimension, separation and distance of the dissimilar views, a spectator without inconvenience may exercise that amount of convergence which is necessary for him in order that the singly presented images shall fuse perfectly with what he accepts to be the best degree of relief. *Optimum convergence* as thus defined by the quality of the visual result is the second essential condition of stereoscopy.

Apparently every method of stereoscopy must meet these two conditions, single presentation and optimum convergence, as minimum requirements. It has never been difficult to meet either one or the other of these conditions, but having satisfied one of them it has always proved problematic how to satisfy the other without introducing objectionable features into the visual process or resorting to instrumental means that were technically difficult and commercially impracticable.

The methods that have been used hitherto in projection stereoscopy, whether with still or motion pictures, have pro-

[2] Methods of measuring eye movement such as have been worked out by Judd and by Dodge probably offer the best approach to this problem.

ceeded upon the plan of satisfying first the condition of optimum convergence and have then dealt with that of single presentation by means of special devices. Thus convergence has regularly been met by projecting the two dissimilar views upon approximately the same screen area, this principle of identical position or more literally of superposition being effective for the purpose because in fixating any part of this projection area the eyes are necessarily converged and always with sufficient approximation to optimum convergence. But correct convergence is not in itself sufficient as may be noted if the dissimilar views thus objectively superimposed are observed by free vision. Under this circumstance double instead of single presentation would obtain and the perceived result is a composite view which is anything but stereoscopic.

For satisfying single presentation when the convergence condition is met by projecting the views in superposition on the screen various procedures are known, each having certain advantages and limitations. One such procedure, by complementarily colored light filters so utilized in projecting the pictures and also by each observer in viewing them that light from only one of the pictures can enter each of the eyes respectively, is too well known to require comment. Another, known commercially as Teleview (3), is by rapid alternate interruption of the two projected views with synchronized alternate occlusion of the eyes by means of an electrically controlled shutter revolving before the face of each spectator. In this procedure one eye is exposed for such time as its proper picture is shown on the screen area, the other eye and picture being eclipsed until the situation is reversed in their behalf. Although this is strictly a method of monocular vision alternating at high speed for the eyes, the resulting depth effect under favorable conditions is good. How good it is, however, cannot be said because as yet no scale exists for comparing the degree of visual depth obtainable of the same subject matter by different methods of stereoscopy. Still other procedures that make use of superposition to meet the requirements of convergence are at present being experimented with. A principal aim in these researches is to

be able to dispense entirely, if possible, with a viewing device for the individual spectator. This will involve meeting the full requirements of stereoscopy experimentally but in ways more strictly objective and independent of the observer than those above mentioned. If this can be done in a simple and effective way it should mean as much to visual science as it undoubtedly will to the motion picture industry.

In contradistinction to the above methods for stereoscopy prismatic methods comply with the same requirements but in the reverse order. Instead of first providing for convergence and then devising means for single presentation, the procedure in prismatic methods is first to provide for single presentation and then to employ special means for securing optimum convergence. Single presentation offers little difficulty when prismatic means are to be used because the dissimilar views are always shown separate from one another and each monocular field can readily be restricted by screens in the stereoscope so that only one view is presented to each eye.

This objective arrangement of the views in separate locations is familiar to us all from the binocular slides used with the lenticular stereoscope. The same principle, however, is applicable in projection stereoscopy, the views being projected on adjacent screen areas, *i.e.*, in juxtaposition rather than in superposition. In this case dissimilar views of large dimension are juxtaposed in fixed positions on the screen and are singly presented to the eyes. The problem of optimum convergence then is to find instrumental means whereby any observer without ocular effort can cause virtual images of the views to move toward one another in his vision field so that these singly presented images will progressively superimpose and finally (at the point of optimum convergence) will fuse to be a unitary image in full relief. Briefly, with juxtaposed views as the point of departure the key to projection stereoscopy is *controllable image displacement.*

Before turning to consider methods for obtaining gradable image displacement it should be noted that different forms of juxtaposition, horizontal or vertical, may be used in pre-

senting pictures on the screen, as indicated in Fig. 1. The ultimate stereoscopic result when the singly presented images are brought into perceptual conjunction will be the same whatever form of juxtaposition is used, and the technique of image displacement will also be essentially the same. Choice in the form of juxtaposition to be employed will therefore depend in part upon points that arise in the taking and projecting of the pictures. Thus in order to take dissimilar motion pictures on a single film such as may be operated in a standard projector we have found reversed horizontal juxtaposition to be convenient although single presentation is then less easy to arrange, and the film pictures are, of course, somewhat less than half the size of a frame of the film.

From the standpoint of perception vertical juxtaposition [1] has three advantages over any type of horizontal juxtaposition. First, with rectangular pictures (such as are given by a full frame of standard film) the amount of separation of corresponding parts of the pictures is greater in the horizontal than in the vertical position, and for persons very close to the screen the former may necessitate an excessive amount of image displacement [2] in order to unite the images. Secondly, for observers situated considerably to one side of the screen the nearer of two horizontally placed pictures (which are of equal size on the screen) subtends an appreciably greater visual angle than the more remote picture, whereas this apparent discrepancy in size is greatly lessened for observers so situated if the pictures are presented vertically. Although the eyes have considerable tolerance for size discrepancy in images that are to be stereoscopically fused, this factor, if too pronounced, will interfere with the 'fit' of the images when conjoined. Thirdly, because for most persons voluntary antagonistic eye movement (convergence) is possible only in the plane of the interocular axis,[3] it is necessary to rely wholly

[1] In the case of vertical juxtaposition it is immaterial which of the dissimilar views is shown above or below provided that they are presented singly to the proper eyes. Our practice has been to have the right eye aspect always the lower on the screen.

[2] Prismatic displacement of each image up to a maximum of from 15 to 18 deg. can usually be tolerated without seriously affecting the quality of fusion.

[3] Although the eyes can readily be converged in the plane of the interocular axis

upon instrumental control of image displacement when fusing views presented in vertical juxtaposition. On the contrary, when dealing with pictures in the horizontal position an

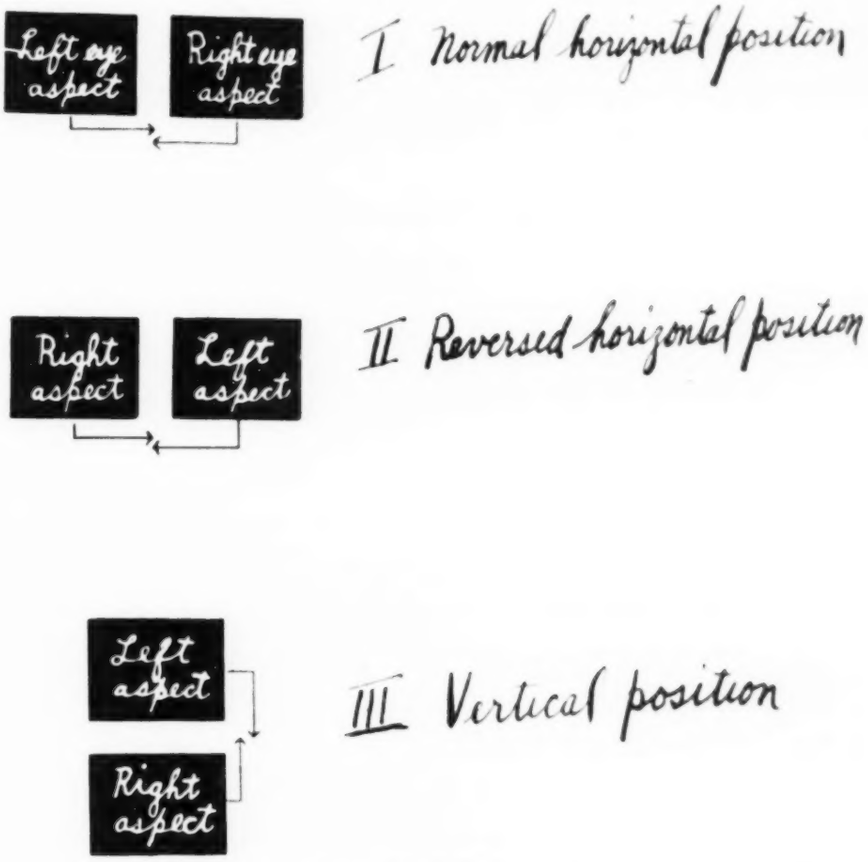

FIG. 1. Types of juxtaposition on screen

observer may unwittingly use considerable ocular motor adjustment instead of an exclusively instrumental control in effecting fusion. From an experimental standpoint this muscular contribution to convergence is gratuitous and undesirable, and if it be too great or too long sustained it may involve more or less ocular strain. With vertical juxtaposition, however, voluntary or reflex ocular movement to implement convergence is practically eliminated, with the result that precise objective control of image displacement is rendered possible.

to an extent of 10 or even 15 deg. from the direction of parallel vision, it is not ordinarily possible to look upward with one eye and downward with the other except to a very slight extent (which for our observers was only a fraction of one degree). Moreover, this latter coördination of the eyes besides being small in amount seems to be scarcely at all susceptible to training.

We turn now to methods for obtaining stereoscopic fusion from large views projected in juxtaposition, the problem being to render images of the views mobile so that they may be moved into visual conjunction. Gradable image displacement can be obtained by at least *three* distinct instrumental procedures. Two have recently been developed in this laboratory, and our third is an adaptation of a special stereoscope which Brewster devised for binocular slides which might be of slightly different dimension from the standard size, the object of our adaptation being to provide for single presentation as well as for the control of convergence under projection conditions. The first two of these procedures differ in the type of displacement imparted to the two images in the vision field in order that they may be brought in visual union. One employs *direct displacement*, *i.e.*, the image of each juxtaposed view is moved in a straight line direction across the field of vision directly toward the other image until they unite; the other employs *circuitous displacement* wherein the images are each moved on a circular locus of given radius and come into stereoscopic conjunction where these loci intersect. These procedures for image displacement will be dealt with in turn.

The failure of the ordinary prismatic stereoscope to satisfy optimum convergence under projection conditions is easily appreciated. The favorite lenticular type, which not only displaces and fuses the images of binocular slides but also magnifies them, is disqualified because in this case in order to have the presented subject matter in focus it must be at the focal distance of the lenticular prisms, *i.e.*, a few inches from the eyes. If plane glass prisms are substituted for lenticular prisms in an ordinary stereoscope this difficulty is overcome but another is encountered. Juxtaposed views on a screen can be successfully fused with plane prisms of given refractive power provided they be used by the observer at a particular distance from the screen. Should the observer approach or retire from this position his images of the objective views are at once moved out of visual conjunction owing to the image displacement by the prisms being of fixed

angular amount, *i.e.*, ungradable. Moreover, the distance from the views which is optimum for one observer using the prisms is usually not correct for another, so that another observer would require prisms with a slightly different refracting angle in order to have optimum convergence from that position; and still other prisms would be required with any change in the size or separation of the pictures on the screen. These limitations of glass prisms in respect of meeting the conditions of convergence with projected pictures have rendered the plane prism stereoscope useless commercially and very inadequate for experimental purposes.

An effective remedy is to use a type of prism whose refracting angle can be modified at will. Instead of a prism whose sides are fixed in their angular relation, a prism is required whose plane sides can be manipulated so that they may be parallel or may be inclined toward one another to any required angular extent, thus bringing under full control the direct displacement of an image observed through the prism. Such a flexible prism can be constructed having sides of thin plane glass and between them in a pliable container a transparent liquid medium with fairly high refractive index such as distilled water, glycerine, or a mixture of such liquids. Mounting the prism in bearings whose axial line is a diameter of each prism face allows the refracting angle of the confined medium to be altered at will without changing the volume or pressure (but only the shape) of the liquid contents. These prisms we have found to be durable, inexpensive to make, and very effective for gradably controlling the deviation of transmitted light.

Figure 2 illustrates (*a*) the parts of a flexible prism unassembled, and also different styles of mounting for a loaded prism (*b*) with bearings parallel and (*c*) with bearings at right angles, the latter being the better style for use in a stereoscope.

The angular amount of image displacement obtainable with flexible prisms containing various media was empirically determined by measuring the size of refracting angle required to displace the image of a vertical edge a given angular distance in the field. There are small but appreciable individual

FIG. 2. Flexible liquid prism. (*a*) Parts, (*b*) bearings parallel, (*c*) bearings at right angles.

FIG. 4. Flexible prism stereoscope. Upper, for pictures in normal horizontal juxtaposition: (*a*) Rear view, (*b*) front view, (*c*) front view in case. Lower, for pictures in vertical juxtaposition: (*a*) Rear view, (*b*) front view, (*c*) case, rear view.

FIG. 5. Rotary prism stereoscope. (*a*) Parts for one barrel, unassembled. (*b*) complete mounting with plane prisms, rear view. (*c*) fitted with lenses for magnification.

FIG. 6. Sliding lens stereoscope. (*a*) Case, (*b*) rear view, (*c*) front view

differences in readings by different observers under like objective conditions. The curves A_1, A_2, A_3, in Fig. 3 are typical results with water and different mixtures of water and glycerine as media. For comparison curve A_4 was plotted using a set of plane glass prisms having different refracting angles. The curves B_1, B_2, B_3 in Fig. 3 indicate geometrically the angular displacement of images that would be required at various distances from the screen in order to fuse juxtaposed pictures of various sizes, *e.g.*, pictures 15 ft. square separated 2 ft., 10 ft. square separated $1\frac{1}{2}$ ft., or 4 ft. square separated 1 ft. Reading the *A* curves in conjunction with the *B* curves, and accepting (on experimental grounds) that fluid prisms will displace images effectively for purposes of stereoscopy up to a maximum deviation of 15 deg., it may be seen from the graph that pictures of the size B_3, for example, can be successfully fused by an observer at any distance from the screen to a minimum distance of approximately 10 ft. etc.

Our first method for projection stereoscopy with juxtaposed pictures is by means of a flexible prism stereoscope.

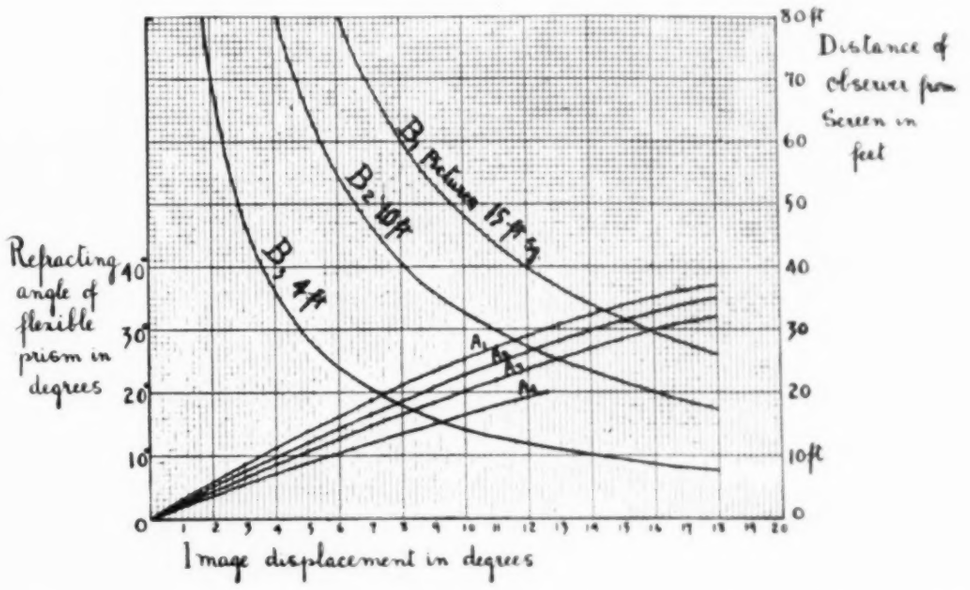

FIG. 3. *A*. Angular displacement of an image by liquid media in a flexible prism *B*. Image displacement required for fusion of projected juxtaposed pictures.

Medium A_1—100% water — Pictures B_1—15 ft. square, separated 2 ft.
" A_2— 50% " , 50% glycerine — " B_2—10 ft. " , " $1\frac{1}{2}$ ft.
" A_3— 20% " , 80% " — " B_3— 4 ft. " , " 1 ft.
" A_4—solid prisms of crown glass

This instrument consists of two liquid prisms mounted in a case with a screw attachment which controls the size of their refracting angles to give optimum convergence and also synchronously controls the movement of the eye-screens in the stereoscope to maintain proper single presentation of the images at all times. Instruments of this type, as variously illustrated in Fig. 4 with the prisms unloaded, will permit an observer at any ordinary distance to fuse at will views of any reasonable size juxtaposed vertically or horizontally merely by turning the adjusting screw, thereby bringing the images together by direct displacement until they unite stereoscopically.[1]

Our second prismatic method for fusing projected material employs ordinary plane prisms of glass so arranged that the requirement of optimum convergence is met by circuitous displacement of the images. When any object is viewed through a rigid prism of given refracting angle an erect image is observed which is displaced a fixed angular amount toward the refracting edge of the prism. If, however, the prism is rotated in the plane of its axis, this image remains erect but moves in a circle whose radius is the aforesaid displacement, the direction and rate of movement of the image being the same as the direction and rate of rotation given the prism. In order to move the images of two juxtaposed views into full visual conjunction by this procedure it is merely necessary to put before each eye a prism of like and of sufficient[2] refracting power and to rotate the prisms synchronously in opposite directions. Thus for views in the horizontal position, if the prisms are placed before the eyes with refracting edges downward and are then rotated the one clockwise and the other counterclockwise, the erect images, at first directly below each objective picture, are made to approach progressively along their respective circular loci and they fuse in

[1] Should the images require any adjustment for alignment when they are being moved into conjunction this may be secured by tilting the stereoscope slightly in the plane of the face on its base of support, a pivot mounting being provided for this purpose.

[2] Prisms must be used that will displace each image at least one half of the total angular distance which corresponding points in the pictures subtend to the position occupied by the observer.

relief when this movement along intersecting paths brings them into conjunction.[1]

To apply this prismatic principle in projection stereoscopy[2] suitable plane glass prisms may be placed in holding rings which are mounted to be rotatable within short metal barrels, the prisms being so coupled (*e.g.*, by a crossed cable) that they may be rotated contrariwise in unison. Single presentation is met by having the barrels independently movable so that each may be directed towards its proper view and occlude the other, this adjustment being applicable for any form of juxtaposition of pictures. This is a rotary prism stereoscope, and the form of construction which we now use is illustrated in Fig. 5, (*a*) and (*b*). Magnification of projected subject matter, if this is desired, may be had with such a stereoscope by inserting an opera-glass eyepiece on one end of each stereoscope barrel with the objectives telescoping over the forward ends of the barrels, the rotatable prisms being immediately in front of the respective eyepieces as in Fig. 5 (*c*).

Finally, in our instrument which incorporates Brewster's conception of a 'universal stereoscope' (5), direct image displacement is again used. The technique in this case is to employ a concave and convex lens of like curvature before each eye. If an object is observed through these when they are exactly superposed the image is of natural size and without displacement in the field. When, however, one of the lenses

[1] To use one rotatable prism before each eye is the simplest way of securing gradable displacement by circuitous movement of images. The latter principle, of course, is capable of great elaboration. Thus, using two plane prisms in tandem before each eye, one stationary and one rotatable, the amount of ineffective displacement can be reduced and the effective displacement of each image toward the other increased so that circuitous displacement is thereby rendered more akin to direct displacement as given by a flexible plane prism. And indeed, two plane prisms in tandem can be made to displace an image gradably in a straight line direction, viz., by having the prisms of like power with their refracting edges facing away from one another and then rotating them synchronously and oppositely. Although these amplifications of the principle of the rotatable prism are often of great convenience in optical work, they are not essential for purposes of practical stereoscopy and will not be dealt with in further detail here.

[2] Since writing this article we find that the principle of the rotatable glass prism has previously been applied in a very simple form in the hand stereoscope for use with commercial stereoscopic slides (4).

is slid across the other the result is optically equivalent to changing the refracting angle of a plane prism, *i.e.*, the image remains erect and of natural size but suffers direct displacement in proportion to the amount of movement by the sliding lens. A pair of such lenses mounted before each eye with a suitable mechanical means for sliding one lens of each pair and for synchronously moving the eye-screens essential for single presentation will permit projected pictures to be fused from any ordinary distance. Fig. 6 illustrates the construction of a sliding lens stereoscope which we use for pictures in horizontal juxtaposition.

The flexible prism, rotary prism and sliding lens types of stereoscope are three prismatic procedures for gradably displacing the images of juxtaposed pictures in order to effect optimum convergence for any observer situated at any distance. The respective merits of these procedures depend upon the purpose in hand, the flexible prism, in our opinion, being preferable in many ways for experimental work. They all possess the disadvantage of every prismatic method in that imperfections such as the chromatizing and curving of edges and stretching of the images are introduced when the image displacement is excessive in amount.[1] On the other hand the advantages which these methods based upon juxtaposition possess over those based upon superposition of the views are very considerable on the scientific side because of the greater facility for objective control and measurement when the projected views are separate one from the other.

1. *Phil. Mag.*, Vol. III., fourth series, No. 15, Jan., 1852.
2. *Phil. Transactions of the Royal Society*, 1838 and 1852.
3. U. S. Patent, No. 1,435,520, Nov. 14, 1922.
4. U. S. Patent, No. 401,807, Apr. 23, 1889.
5. Brewster, 'The Stereoscope, its History, Theory and Construction,' London, 1870, p. 124.

[1] The quantitative investigation of these defects in color and form (and the correction of them) afford interesting problems in psychological optics, but ordinarily these features are not of practical consequence in stereoscopy.

SYNÆSTHESIA IN THE DEVELOPMENT OF THE CONCEPT

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This paper is a continuation of a prolonged study of synæsthetic processes in the mental life of a blind subject.[1] The procedure during this research has been to compare introspective reports from the synæsthetic subject with corresponding reports from other subjects obtained under similar experimental conditions. In this particular unit of the investigation T.D.C.'s reports were checked against introspections obtained by Fisher in her study of the concept and the experimental method employed was essentially Fisher's.[2] The specific aims of the present study were to ascertain the functioning of *O*'s synæsthetic imagery in the development and use of the concept; to determine, if possible, whether this imagery proved to be essential to the concept; and to discover whether the presence of synæsthesia in the mental life of the subject brought to light any material variations in the facts pertaining to the concept as indicated in Fisher's study.

The material used in this investigation consisted of eight nonsense objects, constructed from modeling clay, and given the type name of 'mipa.' These eight objects were similar in general form. Each consisted of 3 segments: a flat body, from

[1] Wheeler, R. H., 'Visual Phenomena in the Dreams of a Blind Subject,' *Psychol. Rev.*, Vol. 27, 1920, 313–322. 'The Synæsthesia of a Blind Subject,' *Uni. of Ore. Pubs.*, Vol. 1, No. 5, 1920, 61 pp. Wheeler and Cutsforth, 'The Synæsthesia of a Blind Subject with Comparative Data from an Asynæsthetic Blind Subject,' *Uni. of Ore. Pubs.*, Vol. 1, No. 10, 1922, 104 pp. 'The Rôle of Synæsthesia in Learning,' *Jour. of Exper. Psychol.*, Vol. 4, 1921, 448–468. 'Synæsthesia and Meaning,' *Amer. Jour. of Psychol.*, Vol. 33, 1922, 361–384. 'Synæsthesia, a Form of Perception,' *Psychol. Rev.*, Vol. 29, 1922, 212–220. Cutsforth, 'The Rôle of Synæsthesia in Reasoning,' *Amer. Jour. of Psychol.*, Vol. 35, 1924.

[2] 'The Process of Generalizing Abstraction and its Product, the General Concept,' *Psychol. Monog.*, Vol. 21, 1916, 213 pp.

one end of which there projected a circular loop, and from the other a horn-like extension which curved upward, outward, and then downward, finally terminating against the under side of the body. In individual mipas these constantly recurring segments varied in size, not only in absolute amounts, but relative to each other, and possessed certain peculiarities that might or might not be repeated in different specimens. For example, certain of the bodies were ribbed; others were smooth; some had large ribs; and others had small ones. Knob-like projections appeared on certain of the circular loops (doughnut-segment), but not on others, and some of the loops were grooved. On the horn-projection at the other end, there sometimes appeared subsidiary horns, and occasionally concave alterations in surface.

The observer sat at a table with his hands open, palms upward, into which the experimenter placed a mipa at 10-second intervals. Meanwhile the observer rapidly inspected the objects, tactual-motor fashion, and under the following instructions: "I shall present to you a series of mipas. You are to examine each one carefully. At the signal, 'stop,' I shall take the mipa from you and give you another. Upon finishing the series, you are to introspect in detail upon your procedure."

At the beginning of each subsequent sitting, the observer was given the following instructions: "Tell me all you know about mipa, and then introspect upon your recall." At the end of each subsequent sitting he was asked, also, to introspect on his comprehension of a sentence in which the word, mipa, was used. The following are typical sentences. "I was walking along the sidewalk and stepped upon a mipa." "I reached into a collar-bag and pulled out a mipa."

Owing to the unusual rapidity with which the concept of mipa developed and became attenuated, only four sittings of one hour each were undertaken, during which time there were six presentations of the series. The original experiments were performed during February and March, 1922. In November, a final test was made, without presentation of the objects, in order to ascertain if *O*'s imagery had undergone any

striking change. There had been practically no simplification during this interval.

There are here presented one introspective report on *O*'s inspection of the mipas, one on his recall, and one pertaining to the meaning of a sentence in which the word, mipa, appeared:

1. First inspection. Feb. 2, 1922. "Upon hearing *E*'s instructions, I set up for myself the *Aufgabe* to look for general characteristics. . . . The instant my fingers came in contact with the body-part of the first mipa, perception developed in terms of a chocolate-brown pressure, mixed with black and dark-grey streaks of kinæsthesis from finger movements. At one end of the body there suddenly appeared two grooves perceived in terms of fleeting colorations of chocolate-brown curving around the under surface of thumb and forefinger of the right hand; but these colors gave way at once to a smoky-white, tinged with blue, rapidly assuming the contour and shape of visualized grooves. (The bluish, smoky-white is the synæsthetic quality of the 'Mi'-sound of mipa.) Then the perception of the body-part clarified as to shape and size, still in terms of synæsthetic pressure and kinæsthesis. As the inspection continued, the black of the kinæsthesis came more and more to dominate over the chocolate-brown of the pressure. For some time awareness of each mipa was dominated by the body-segment. As the procedure continued, consciousness of other parts took the form of extensions and variations in this chocolate-black mass. My perception of the loop-segment developed as a pear-shaped hole of neutral grey at one end. This hole expanded, contracted, or lengthened, as the case might be, when moving my fingers rapidly over the different mipas. Momentarily there would stand out a black-brown visualization of a doughnut-shaped ring, much lighter in color than the body-segment, and this was interpreted to mean that the part under inspection was lighter in weight than the middle part. Irregularities and various types of projections at the other end of the object appeared in terms of brown knobs projecting out, like pyramids, from the body. These knobs were edged with the black of kinæsthesis. Sometimes I perceived these irregularities in terms of deep brown or black rings and ridges. Frequently similar visualized projections appeared on the body-part, which latter, by this time, had become more and more of a bluish, smoky, white, at the end opposite the loop. Here the color was more intense at the base of the horn-like projection, where I originally detected the grooves. The only association which I recall, was the appearance, early in the inspection, of a brown, oblong area, surrounding the neutral-grey hole at the ringed end of the mipa. This was a synæsthetic appearance of the meaning, plasticene clay."

2. *Recall.*—Fourth sitting: March 11. "A mipa is an object segmented into three parts. The middle section varies a great deal in shape and size, but is generally flat on top and may or may not support irregularities as a groove, or an indefinite number of knobs, or ridges. To the left is a neck, protruding from the edge of the middle segment and bending down over the latter until it smooths out on the under surface.

"On giving a definition of mipa, I was merely finding words which fitted a series of visual images among which latter there persistently appeared a 'type' image—a stereotyped form, divided into three segments. The first consists of a curved, neck-like appendage about three inches long and about three quarters of an inch wide, extending from the left end of the body-part around and beneath, ending more or less

abruptly near the under surface of the body. This image is tri-dimensional. The body part is visualized in black, the neck in a dull, tactual yellow; very little, light, smoky-blue color lingers about the base of the neck. The body part appears to be about two inches wide, three or four inches long, and about one half inch deep. The dull, sooty black is uniform throughout and tridimensional with the brightness quality visible throughout its depth. These two segments appear together. The third is detached and attention to it is given at the expense of the other two segments. It appears as a ring-shaped figure with outside dimensions about three inches across, resembling an elongated doughnut with a hole about one and one half inches wide. This figure is colored the same tactual yellow as the neck. The hole is neutral grey. Meaningless grey coloration extends off from the side of this ring, which would otherwise have been attached to the middle segment. The entire imagery appears at about arm's length from me, in front, in a neutral grey and entoptic colored setting. In it I see no variable or differentiating features of individual mipas. My attention, throughout, is centered upon the repeated features.

"Under the *Aufgabe* to recall the variable features of mipa, synæsthetic imagery of horns, ridges and indentations appear in a mixture of tactual-yellow, brown, and kinæsthetic black. This imagery rides upon a curdled dark area hovering about the type image. This area is black with indefinite kinæsthetic imagery of finger-movements of exploration. Occasionally the type image, under this same *Aufgabe*, changes in size and shape; but these fluctuations are exceedingly shifty and vague. The quality and brightness of coloration also varies. In all of these shiftings, the type image tends to disintegrate. In its place there appear separated masses of yellow, brown, and black coloration which constitute residual, tactual and kinæsthetic memory-images of individual mipas. If these detached features are to be identified, they must appear on the concrete, visualized segment to which they originally belonged. They never appear definitely attached to the type image."

Second sitting: February 11. Comprehension of the sentence: "I reached into a collar-bag and pulled out a mipa." "As the experimenter read the first few words of the sentence, synæsthetic perception of his voice stood out in bright, silvery grey forms hovering in the center of the visual field close to my head. Adjacent to these forms there appeared a circular halo of kinæsthetic black, which was interpreted as a feeling of expectancy—a waiting for something. When he spoke the words, 'collar-bag,' there was a sudden shift of visual attention to the left where there appeared a visual image of my hand moving downward into the neck of an opened laundry bag hanging from the right handle of the top drawer in my dresser. The hand was colored a tactual-yellow and was visualized no farther than the wrist. The outstanding features of the laundry-bag were the draw-strings, the wrinkled neck and the shadows between the folds. This imagery was in grey and white. A few inches below the draw-strings the bag faded into a grey and peripheral, entoptic setting. In response to the words, 'pulled out,' the hand began to move upward as if being withdrawn from the bag. No sooner had this movement commenced, however, when I perceived the word, mipa, in terms of synæsthetic coloration chiefly of the light, smoky-blue of the 'mi'-sound. Instantly I saw, hanging from the fingers of my hand the ringed, third segment of a mipa. This image was rich in tactual-yellow and black, kinæsthetic streakings. (The imagery was so clear that it would have been possible to estimate from it the supposed weight of this segment.) The black streakings were concentrated on the under surface of the ring, next to my fingers. All of this imagery was detached from my actual hand, and localized about two feet in front of me, in about the same position as my hand and the laundry bag would be if I were actually reaching for a collar."

Introspective data clearly show that synæsthetic imagery functioned at the outset in perceiving the mipa series. While the inspection was tactual and kinæsthetic, no sensations of such a nature developed in the observer's consciousness. They were tactual and kinæsthetic only in significance. As qualities, they were varying shades of yellow, brown, and black, accompanied by an indescribable 'something' which we have chosen to call a 'parent process.' This yellow, brown, and black imagery assumed the form and shape of such parts of the mipas as the observer was inspecting at the time. Along with these colored forms there developed, early in the experiment, a bluish, smoky-white image, localized at the base of the horn-segment. This color was traced to the synæsthetic perception of the syllable, 'mi' of mipa. For a short time this color dominated in such imagery as represented the general meaning of mipa.

Thus we see that not only did synæsthetic imagery appear at the outset in perceiving these objects, but it assumed at once the rôle of the chief mental content in the developing concept. For a time it functioned in the comprehension both of specific and general features of the stimulus.

Various meanings accrued to these visual images. Tactual experiences were yellow; temperature experiences were brown, and kinæsthetic were black. The name, mipa, was represented in the bluish, smoky-white coloration localized at the base of the first segment.

Boundaries between one segment of a mipa and another were, for the most part, indistinct, and such regions as were not clearly perceived were represented in visual imagery by neutral gray areas which blended with a gray, visual setting, varied here and there with entoptic colors. Otherwise the size and shape of the imagery conformed fairly well with the size and shape of the actual object. All imagery was localized in the region of the hands during inspection.

Attempts to recall individual mipas resulted, from the outset, only in partial success. They consisted largely of efforts to piece detached visualized forms into organized units, but the imagery was invariably fragmentary, vague, and

shifting. Such attempts sufficed only to hasten the development of a type-image which soon represented the entire series.

This type-image began with the bluish, smoky-white coloration mentioned heretofore. It gradually broadened out to include the remainder of the middle segment and all of the third and ringed segment. This image became very clear cut and sharply contrasted, in its tactual yellow, from the neutral gray and entoptically colored setting. The development of this image made it still more difficult for the observer to recall individual mipas. When such an attempt was made, the details would not appear upon any given segment of this image but rather above or below it, and differences in meaning between the type-image and concrete memory-imagery of individual specimens were always identified by the appearance of hazy, amorphous forms—vague recalls of individual mipas—which tended to crowd their way into the positions of the different segments in the type-image.

These memory-images of individual mipas underwent constant changes during the six representations. Features which had been ignored in previous examinations repeatedly dominated *O*'s attention and resulted in alterations or supplementations of his concrete imagery. In fact, this concrete imagery was hardly ever the same from sitting to sitting and frequently underwent radical changes during one sitting. The imagery constituting his type-mipa turned out to be a gradual selection from the more stable and frequently repeated items in this concrete memory-imagery.

For the purpose of convenience, the genetic growth of the concept, mipa, may be divided into three, fairly well-defined stages. The first consisted of the synæsthetic auditory-verbal imagery of bluish, smoky-white, which became localized as an ill-defined end of the middle segment. On either side of this indefinite form there appeared a narrow margin of tactual, yellowish-brown imagery of the adjacent parts of segments one and two. It is evident, from his definition at the time, that *O* depended upon this imagery almost exclusively for the class meaning of mipa.

The second stage was characterized by a growth of this image until it included the three segments as described in the second introspection given above. As time went on, the bluish, smoky-white feature tended to disappear.

The third stage was characterized by the loss of the first two segments and by a clarification of the third. Now and then in his recalls the other two segments tended to appear, but only as indefinite and fleeting patches of coloration. Notice that at the end of the second sitting (introspection three) the meaning, mipa, was represented only as a ringed segment in *O*'s comprehension of a sentence containing the type-name. Finally this ringed segment lost much of its tactual yellow and brown. In fact it became so exclusively kinæsthetic in character that it was localized more often in the region of his hand than in the space before him. No doubt this interesting state of affairs may be traced in part to the greater amount of movement necessary in the inspection of this particular segment.

Perhaps the most interesting result of the entire investigation was the stereotyped and specific nature of *O*'s type-image. In no instance did it suffice as a concrete memory-image of any given mipa. While it was used as an aid in constructing memory-imagery of a single specimen, it was always necessary, apparently, to build up this latter imagery by itself. Visualized details, having to do with individual mipas never attached themselves to the type-image, but hovered in its vicinity until they disappeared or until the observer succeeded in fitting them to other visual images of concrete meaning.

This fact is consistent with the stereotyped nature of synæsthesis in general, and reminds us of the inalterable character of number forms. *O*'s type-image took on many of the characteristics of a number form, although it was perhaps subject to greater attenuation. The segments always appeared in the same positions relative to each other; they were constant as to size and shape; the image, as a whole, was stereotyped as to meaning.

The peculiar relationship of such stereotyped imagery as

this to the problem of meaning warrants particular mention. The abstract meaning of highly synæsthetic imagery is implicit, and in order to make it explicit, the image must evidently undergo a process of elaboration. By an implicit meaning, we refer to one which is not defined in the observer's consciousness at the time. It is meaning only in function and not by virtue of specific mental contents. It is meaning merely as context. It operates as a functional unit in a context of other mental processes, but, as a defined meaning, it does not become a datum of consciousness without additional context. For example, the abstract meaning, 'animal,' may appear in *O*'s thinking as a splotch of yellow synæsthetic coloring. To know that it is animal and not some other meaning, requires an additional effort of attention with an elaboration of the yellow splotch. This elaboration may consist of additional visual imagery such as an ear, or it may develop as the synæsthetic coloration of the word, animal, in whole or in part. The difficulty of apprehending concretely defined meanings in terms of synæsthetic colors explains, perhaps, why *O*'s concept of mipa developed so rapidly. Because the imagery is relatively simple and stereotyped, it lends itself particularly well to the development of abstractions. In this way synæsthetic imagery operates as a substitute for that verbal imagery which, in the relatively asynæsthetic person, is used so extensively in abstract thinking.

In comparing the results of this investigation with Fisher's, the absolute dependence of our observer upon visual processes of a synæsthetic nature becomes most apparent. At no stage in the development of the concept was synæsthetic imagery absent. In every detail of procedure from the most insignificant to the most important, a synæsthetic image was used. This fact confirms our previous conclusion that, so far as the observer is concerned, synæsthetic processes function in every detail of mental life.[1] It is obvious that he possesses no other means of perceiving and no other means of thinking in abstract terms. Further, these facts sub-

[1] *Univ. of Ore. Pub.*, Vol. 1, No. 10.

stantiate our former conclusion that synæsthesia is not an unusual process from a functional standpoint but, on the contrary, is the usual procedure in perception and conception. It is unusual only in the stereotyped use of imagery of one modality.[1]

The results of this investigation confirm Fisher's conclusions in every important respect. In our observer, generality of meaning did not accrue to a peculiar imageless or non-sensory content. On the contrary, in virtue of his synæsthesis, it accrued to one type of process, the visual image. In spite of the fact that in *O*'s consciousness there developed a stereotyped image which meant mipa as a class of objects, we are not warranted in drawing the conclusion that generality of meaning is represented by any unique type of visual image. This imagery developed from experiences with individual mipas. Had only one mipa been presented him of the appropriate size and shape, his synæsthetic imagery of that object might have been similar in every respect to his type-image. Generality, therefore, is a matter of function and not of specific content. In other words, the use he made of this imagery identified it as general, rather than as particular in meaning. More specifically, generality is to be identified by the following criteria: First, a process akin to habit formation in which there is an attentional emphasis upon repeated features of the stimulus, rather than upon variable features. The concept, then, is a direct product of repeated stimulation in the realm of thinking. Second, mental processes are to be employed in contexts where similarities in content and not differences bring the thought process to an end. There is a mental set appearing, perhaps, as an *Aufgabe* to look for repeated features, to use them in the fulfillment of a task, or else there is a predisposition to associate similarities without the intention of making specific use of them. Third, there develops an interpretative process by means of which the observer specifically labels his experiences as general. This interpretative process ranges in degree of complexity from the relatively simple expedient

[1] *Op. cit.*

of elaborating upon a single synæsthetic image by adding to it other visual imagery, to the indirect procedure of characterizing the experience verbally. The complexity of this interpretative period depends upon the observer's *Aufgabe* to label his concepts explicitly, and upon the degree to which the thought process in question has, through habit, become attenuated. If attenuated, the generality of meaning is implicit and not explicit. Fourth, "meaningfulness," consisting generally of kinæsthesis in asynæsthetic subjects is, in *O*, internal movement of the image together with an upward and forward shift of its position.

Our results lead us to stress the importance of kinæsthetic factors more than was done in Fisher's investigation. By this we do not mean to imply that other sense modalities are unnecessary in any particular case, but rather, that as the process of generalization proceeds, the kinæsthetic modality is the most useful upon which to rely. It is simpler in nature and less subject to the variations that are likely to occur in modalities characterized by a greater wealth of qualitative and spatial detail. Moreover, it is the modality most likely to repeat itself in the observation of individual objects and situations. Since generality depends in part upon attentional emphasis of repeated features, the importance of kinæsthesis is to be expected. As an example of this, we point to *O*'s tendency to depend upon a kinæsthesis, synæsthetically perceived and remembered, of the ringed segment of mipa. The bluish, smoky-white coloration which appeared early in the growth of the concept might, so far as its content was concerned, have functioned as the most important definitional cue, but it gave way, shortly, to the black kinæsthesis of the third segment.

To recapitulate, the process of generalizing abstraction and its product, the concept, have been investigated in the case of a blind, synæsthetic observer with the use of nonsense objects made of modeling clay. Introspective reports show that in every detail of procedure this observer depends upon synæsthetic, visual imagery and that synæsthesia in his case, at least, is not confined to processes of perceiving but is

quite as characteristic of conception as well. Further, Fisher's main conclusions have been verified in this case. It has been found necessary, however, to place more emphasis upon the kinæsthetic modality, in spite of the fact that the kinæsthetic quality is known to the observer only through its substitute form of black, synæsthetic imagery.

A DYNAMOGRAPH

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The instrument here described was designed to meet the needs of a test for recording dynamic control as it is found in the playing of certain musical instruments. Its relatively low cost of construction, however, and its adaptability to the registration of various forms of muscular control seem to indicate that it may also be a serviceable piece of apparatus in the general psychological laboratory.

The Dynamograph is a modified form of writing lever, and operates on the principle of a simple lever; the modifications being necessary for the proper adjustment of the writing-point. In Fig. 1, *A* is a baseboard which may either

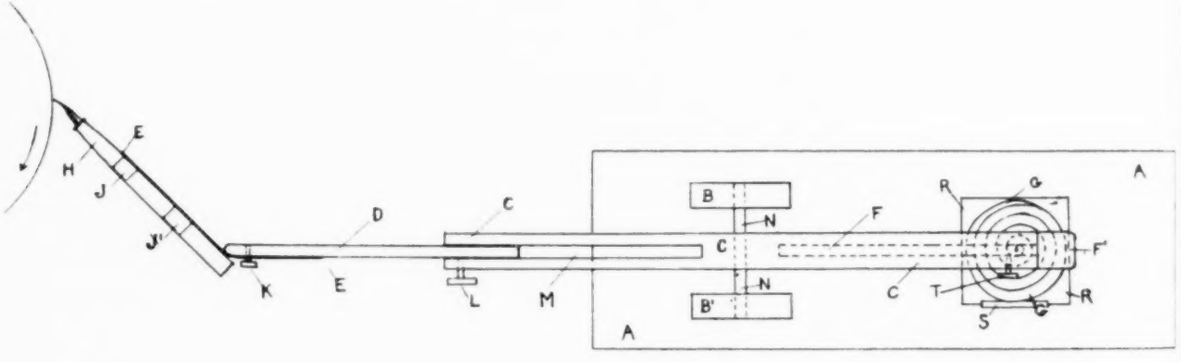

FIG. 1. Top view

be made sufficiently massive to remain fixed when the pressure upon the spring is applied, or, preferably, be made lighter and then clamped to some supporting surface. *B* are the supports for the light, wooden lever *C* which turns upon the axis *N*. *F* is a groove in which an extension of one of the lever-arms moves; *M* is a similar groove for accommodating the extension-arm *D*. Any position of these extension-arms may be fixed by the thumb-screws *L* and *T*. Since *T* has to meet the considerable resistance of the fully compressed spring, the groove

F should be reënforced at the upper and lower surfaces of *C* with strips of brass. This precaution is not needed for the other arm *D*, because this merely supports the very slight resistance of the writing-point. F^1 is the end of the extension-arm *F*. It is cubical, with rounded edges and corners, this

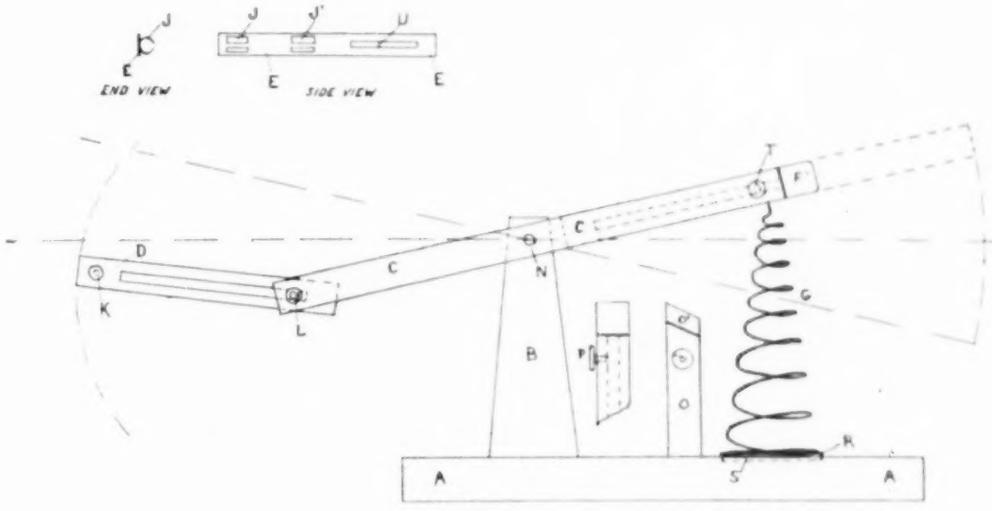

FIG. 1. Side view

shape having been found best accommodated to the finger-positions with which the subjects grasp this lever-end. *G* is a spiral spring, with a maximum resistance, just before the catch O^1 is reached, of approximately four pounds. By attaching the base of the spring to a metal plate *R*, and this in turn to the base-board, the spring may be made interchangeable with other springs of various resistances. By hinging the metal plate as at *S*, and lifting out the upper end from the lever *C*, the spring-resistance may be eliminated rapidly, if this be desired. The catch *O* is adjustable by means of the screw *P* so that the maximum point of compression of the spring may be fixed as desired. *E* is a thin strip of brass (shown detached in the side view) carrying two pairs of 'arms' *J* and J^1 for holding a pen, which, in the figure shown and in Fig. 2, is an ordinary small fountain-pen. *K* is a screw for tightening *E*, in which a groove *U* permits a slight additional extension.

As a result of this adjustment of the extension-arms *E* and *D*, the point of the writing-pen may be brought into contact

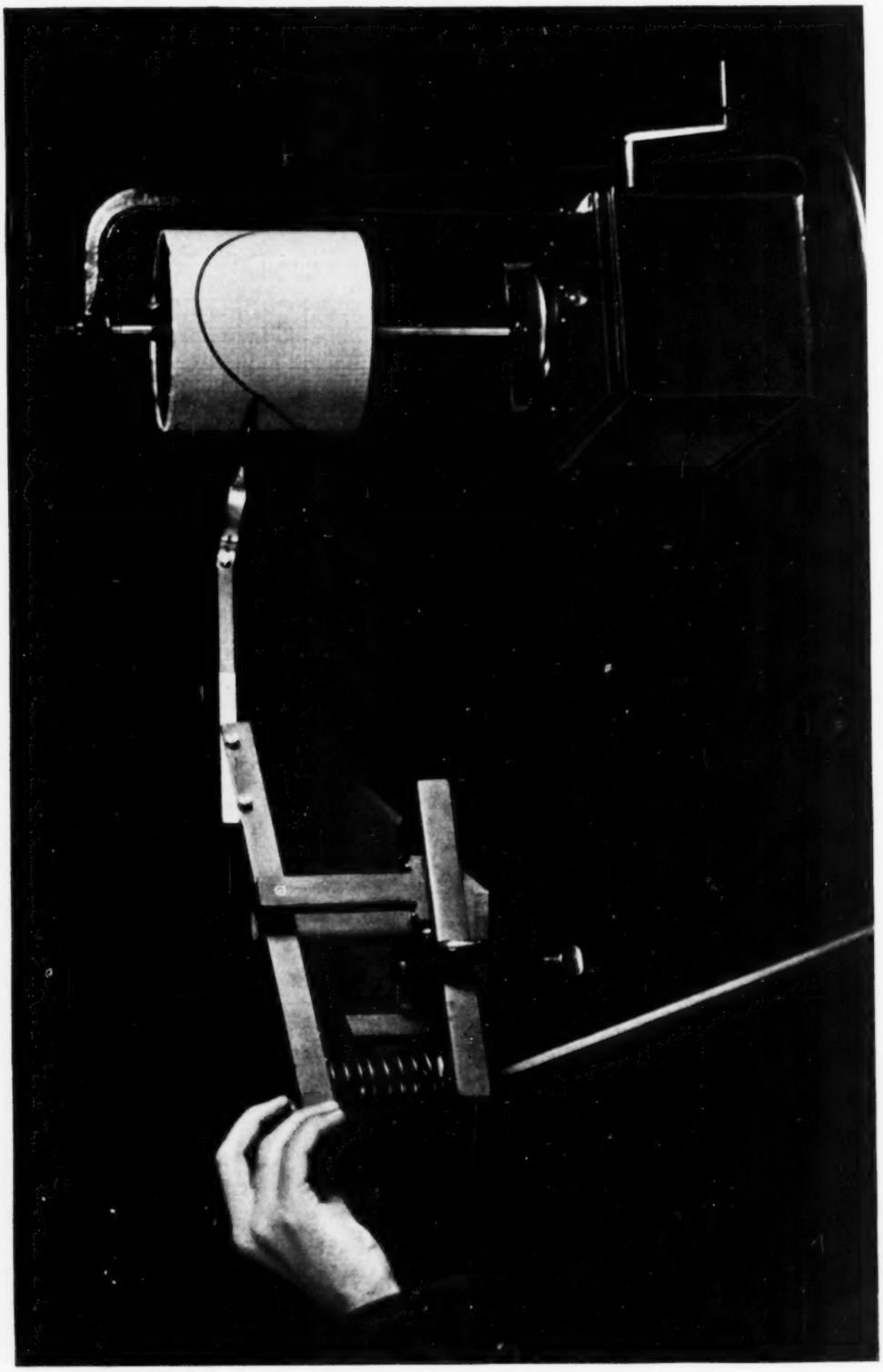

FIG. 2

with the surface of the recording paper at any angle desired. The strip of brass should make an angle of at least 45° with the lever-arm. When the kymograph is in position, this angle will increase somewhat because the pen must be pushed back slightly before a resistance sufficient for writing is secured.

The relationship between the direction of the pen shown in the figures and that of the revolving drum is contrary to the customary arrangement. If the test be given as shown in Fig. 2, this unusual arrangement is necessary. In this test the subject attempts to keep the pen-point on the black line, the elevation of which slowly changes as the drum of the kymograph revolves. Accordingly, it is necessary that the approaching parts of the line be clearly visible before they reach the actual point of contact. So long as the various adjustments are manipulated until the proper degree of resistance is found, this arrangement offers no mechanical difficulty and will not interfere with the adequate writing of the pen.

Figure 2 shows an early model of the Dynamograph in actual use. The pen here shown is a standard form of the small Waterman Fountain Pen, and, when properly adjusted, has given very satisfactory results.

Although the simplicity of the instrument minimizes the danger of unexpected mechanical difficulties during a test, several points should be observed in order to secure efficient operation of the instrument:

1. The pen-point itself must be very pliable. With the pen held in the usual, nearly-vertical, position for hand-writing, it should write when only the weight of the pen-holder presses the point against the paper.

2. The angle which the pen makes with the writing-surface should be as far from a right-angle as possible. Too small an angle is impossible because the hard-rubber ink-feed beneath the pen-point will itself then touch the paper.

3. The pen must always be kept very clean and the flow of ink should be well assured immediately before beginning the record.

4. The instrument is not intended for very rapid vertical

displacements of the pen, sudden shifts of displacement, or for rapid speeds of the kymograph.

5. The brass strip carrying the pen should be bent approximately at one point; the final amount of curvature should not be distributed throughout the length of the brass strip.

6. The angle at which the pen deviates from the horizontal should be as far below the horizontal before pressure is applied, as it will be above when approximately maximum pressure is exerted.

7. The writing paper should be very smooth. Not glazed, however, since glazed paper may not take the ink readily.

8. There must be no 'play' in any joint of the instrument.

9. The plane of movement of the pen-point must be vertical, parallel to the writing surface.

10. The pen should touch the kymograph drum as near as possible to the middle of the half in the subject's field of vision.

The slight disadvantages which the size and weight of a fountain-pen introduce, in the necessity for a finer original adjustment of pen to paper, are easily compensated for by the distinct advantages of the record itself. The labor and inconvenience of the 'smoked-paper' method are eliminated; the constant flow of ink is assured with no danger of blotting; and the record is complete, ready for measurement as soon as it is made. By using graph paper, with millimeter blocks, the reading of any deviation may be made at once without further measurement. Fig. 3 shows two typical records, superimposed upon the same guide-line.

Several ways of measuring the curves are possible. Thus the number of horizontal millimeters during which the tracing-

FIG. 3

curve deviates from the guide-curve, divided by the total number of horizontal millimeters in the guide-curve will give one coefficient of dynamic control. Or the actual amounts of the deviations may be counted and an average deviation calculated. If desired, merely the number of deviations may be counted, as in the usual form of 'steadiness' test. In fact, any curve obtained will give an array of items from which any of the standard statistical measures may be derived.

The Dynamograph lends itself further to any variation, within reasonable limits, in methods of procedure for tests of dynamic control. The extension of the lever-arms will secure any ratio between the two arms. Fluctuations at the key-end, therefore, can be reproduced upon various scales at the writing end. The extension $(F - F')$ of the key-arm likewise changes the resistance of the spring by lengthening the lever-arm. Finally, variations in the thickness or actual form of the guide-line used, as well as those in the speed of the kymograph drum, furnish means of controlling any degree of difficulty for the test.

In tests requiring a guide-line, the reaction is necessarily an eye-hand coördination. The instrument may be used as well, however, without a guide line, for measures of dynamic control independent of the sensations of other sense departments. In such a case the direction of the pen may be reversed, although this is by no means necessary. It merely simplifies the preliminary adjustment of the writing-point.

Should work with constant resistances (weights) be desired, instead of the increasing resistance of a spring, the latter can readily be removed and the weights attached to any point along the other arm of the lever. For this purpose a sliding collar carrying a hook will be found useful.

When the Dynamograph is properly adjusted and operated approximately on the scale given for the figures, readings to one millimeter may readily be made. This I have found sufficiently fine to meet the demands of the test for which the instrument was originally designed.